US007119927B2

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Sugiura et al.

(10) **Patent No.: US 7,119,927 B2**
(45) **Date of Patent: Oct. 10, 2006**

(54) **COLOR CONVERSION DEVICE AND COLOR CONVERSION METHOD**

(75) Inventors: **Hiroaki Sugiura**, Tokyo (JP); **Shuichi Kagawa**, Tokyo (JP)

(73) Assignee: **Mitsubishi Kabushiki Kaisha**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/109,685**

(22) Filed: **Apr. 20, 2005**

(65) **Prior Publication Data**

US 2005/0185840 A1 Aug. 25, 2005

Related U.S. Application Data

(62) Division of application No. 09/689,645, filed on Oct. 13, 2000.

(30) **Foreign Application Priority Data**

Oct. 14, 1999 (JP) 99-291893

(51) **Int. Cl.**
G06F 15/00 (2006.01)
G03F 3/08 (2006.01)

(52) **U.S. Cl.** **358/1.9**; 358/520

(58) **Field of Classification Search** 358/1.9, 358/520, 518, 523, 534, 535; 382/167, 162; 345/600

See application file for complete search history.

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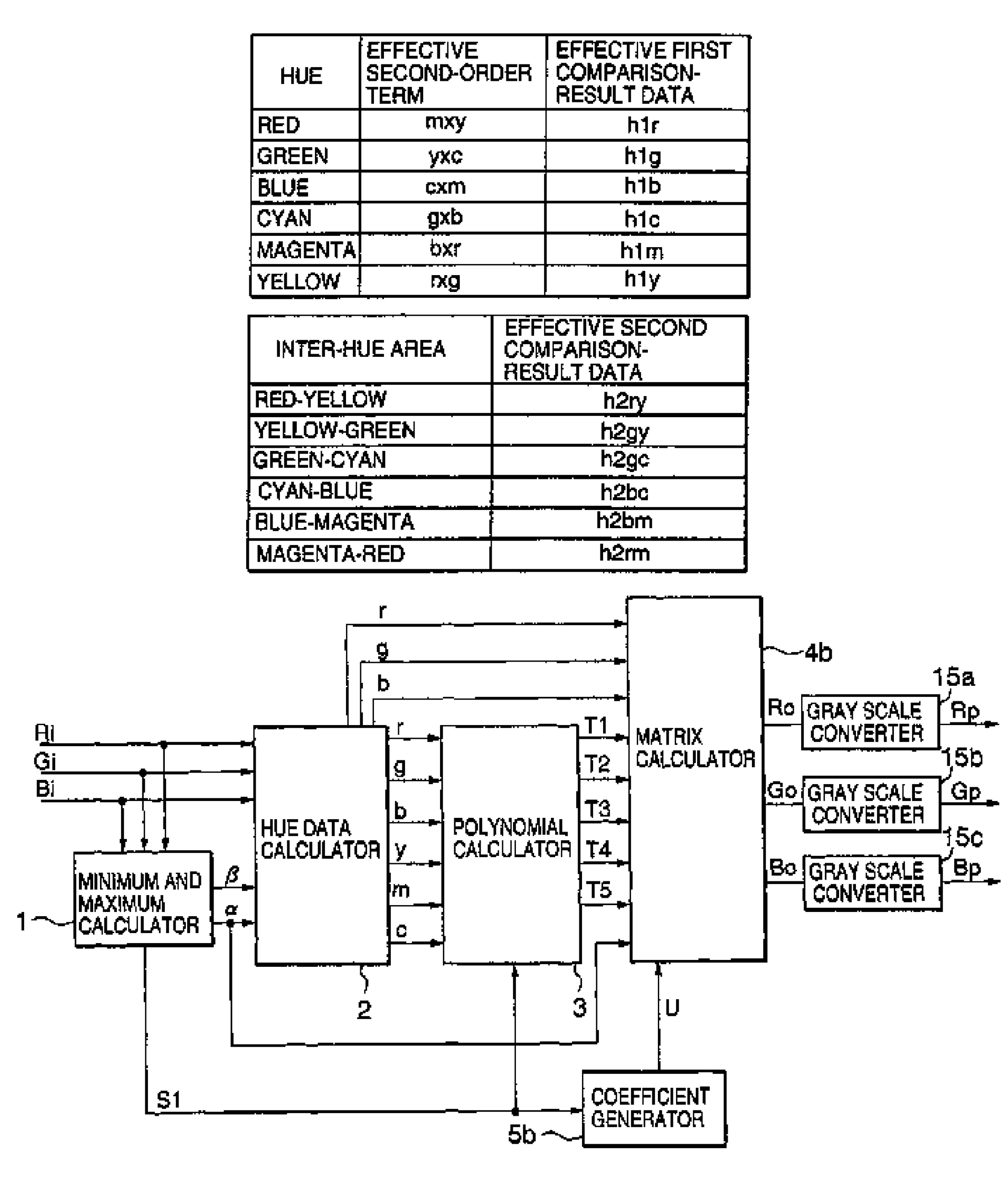
Primary Examiner—Madeleine AV Nguyen
(74) *Attorney, Agent, or Firm*—Birch, Stewart, Kolasch & Birch, LLP

(57) **ABSTRACT**

Responsive to image data of three colors, six hue data are obtained, and then first comparison-result data and second-order terms each relating to one of the six hues, and second comparison-result data each relating to one of the six inter-hue areas are obtained. Matrix calculation is performed on the first comparison-result data, the second comparison-result data, and the second-order terms, using coefficients. By varying the coefficients, adjustment can be made to only the target hue or inter-hue area, without affecting other hues and inter-hue areas. Thus, the six hues and six inter-hue areas can be varied independently, and the large-capacity memory is not required. In addition, gray scale conversion is applied to the result of the matrix calculation, so as to compensate for the non-linearity of the output device.

2 Claims, 20 Drawing Sheets



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JP	7170404	7/1995
JP	8-321964	12/1996
JP	11-17974	1/1999

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FIG. 1

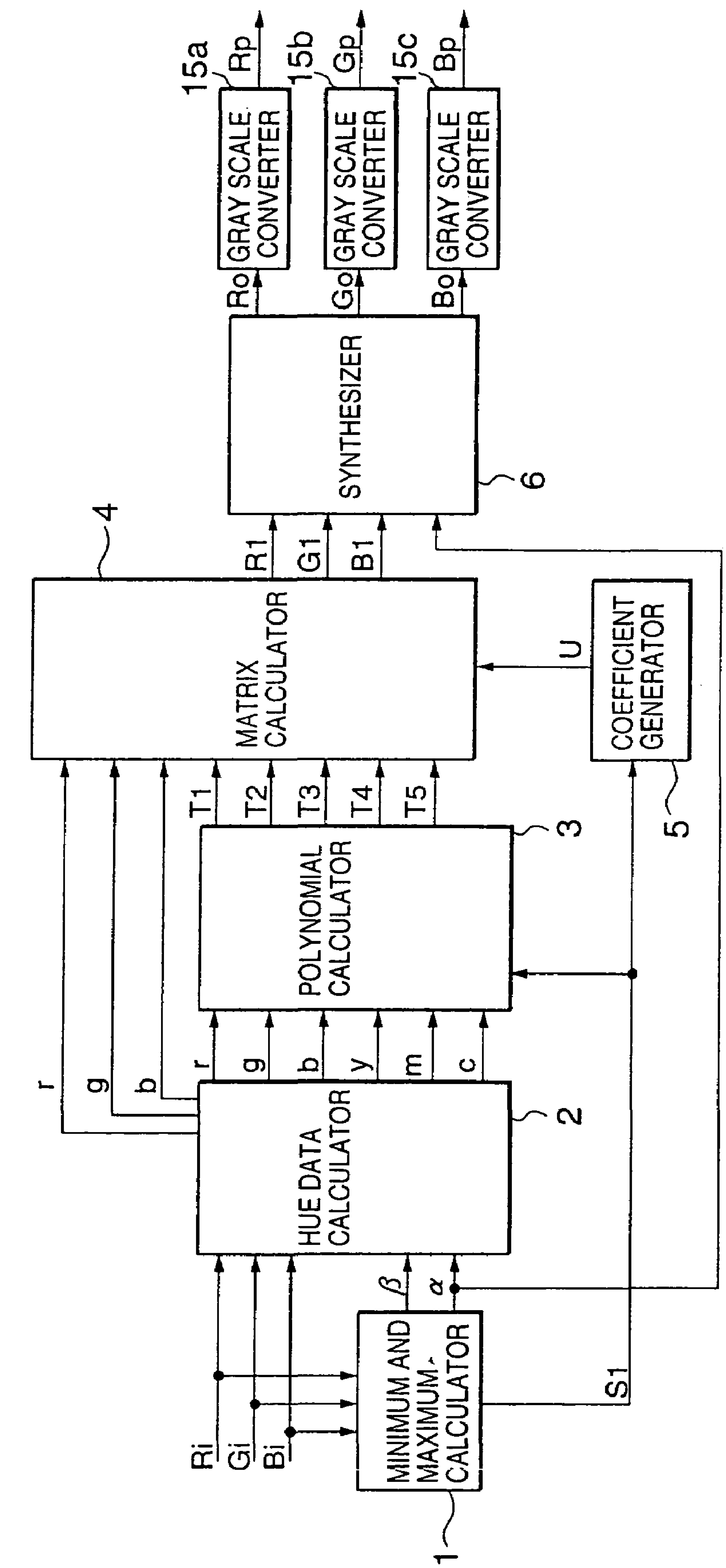

Ri
Gi
Bi
MINIMUM AND MAXIMUM-CALCULATOR
1
S1
β
α
HUE DATA CALCULATOR
2
r
g
b
y
m
c
POLYNOMIAL CALCULATOR
3
T1
T2
T3
T4
T5
MATRIX CALCULATOR
4
U
COEFFICIENT GENERATOR
5
R1
G1
B1
SYNTHESIZER
6
Ro
Go
Bo
GRAY SCALE CONVERTER
15a
15b
15c
Rp
Gp
Bp

FIG. 2

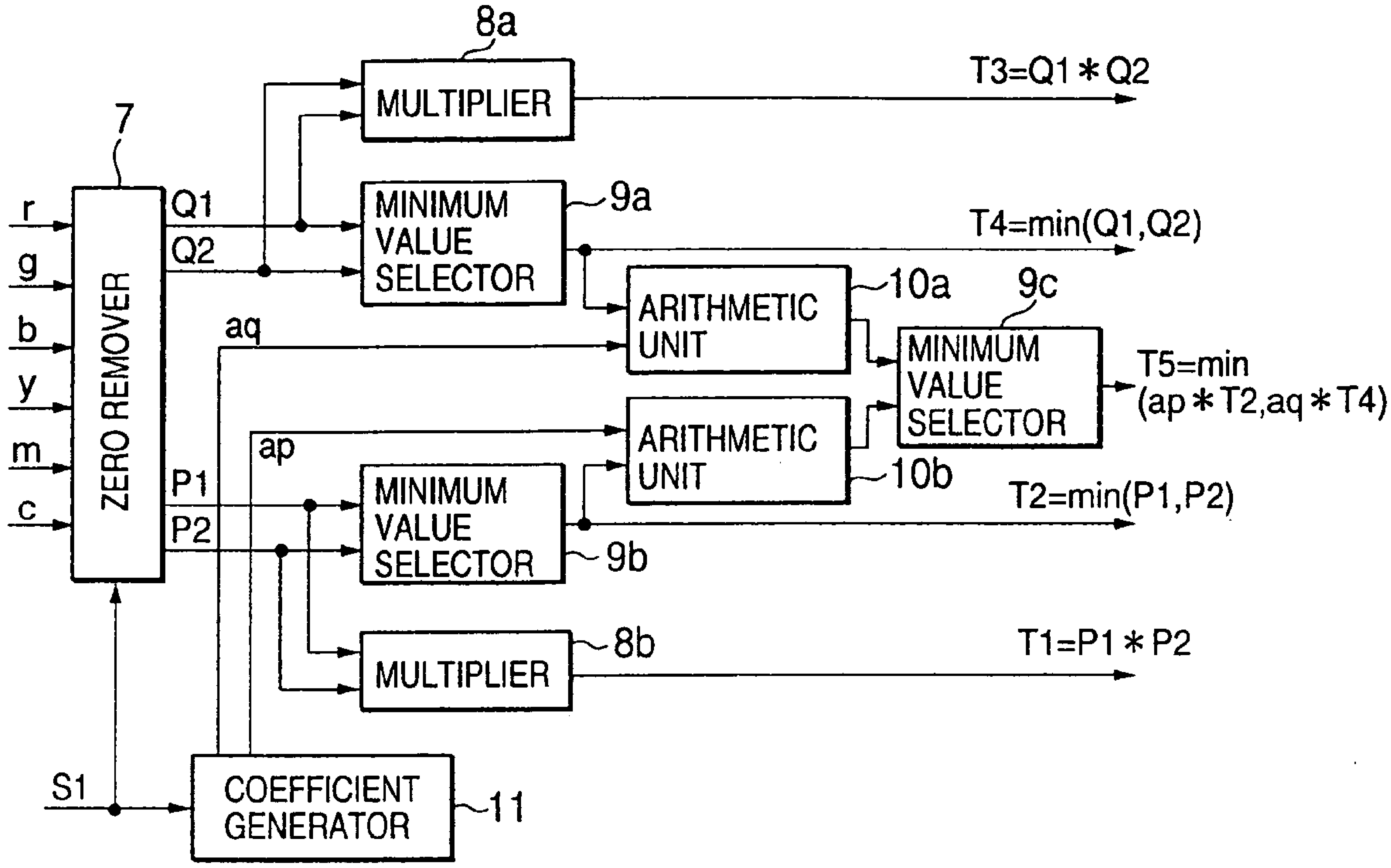


FIG. 3

IDENTIFICATION CODE S1	MAXIMUM VALUE β	MINIMUM VALUE α	HUE DATA OF A VALUE ZERO
0	Ri	Gi	g,c
1	Ri	Bi	b,c
2	Gi	Ri	r,m
3	Gi	Bi	b,m
4	Bi	Ri	r,y
5	Bi	Gi	g,y

* $r=Ri-\alpha$, $g=Gi-\alpha$, $b=Bi-\alpha$
$y=\beta-Bi$, $m=\beta-Gi$, $c=\beta-Ri$

FIG. 4

IDENTIFICATION CODE S1	Q1	Q2	P1	P2
0	r	b	m	y
1	r	g	y	m
2	g	b	c	y
3	g	r	y	c
4	b	g	c	m
5	b	r	m	c

FIG. 5

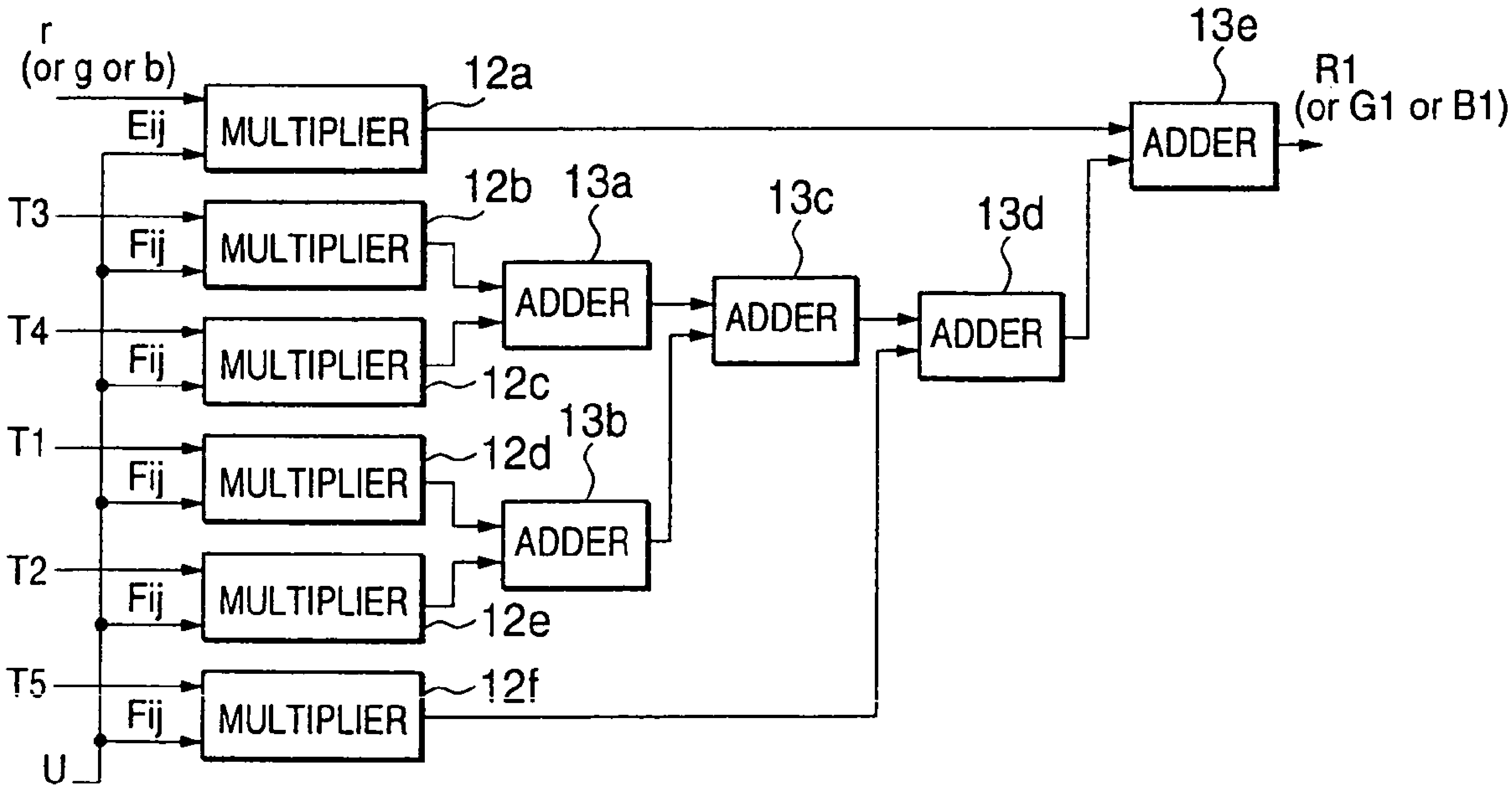


FIG. 6A

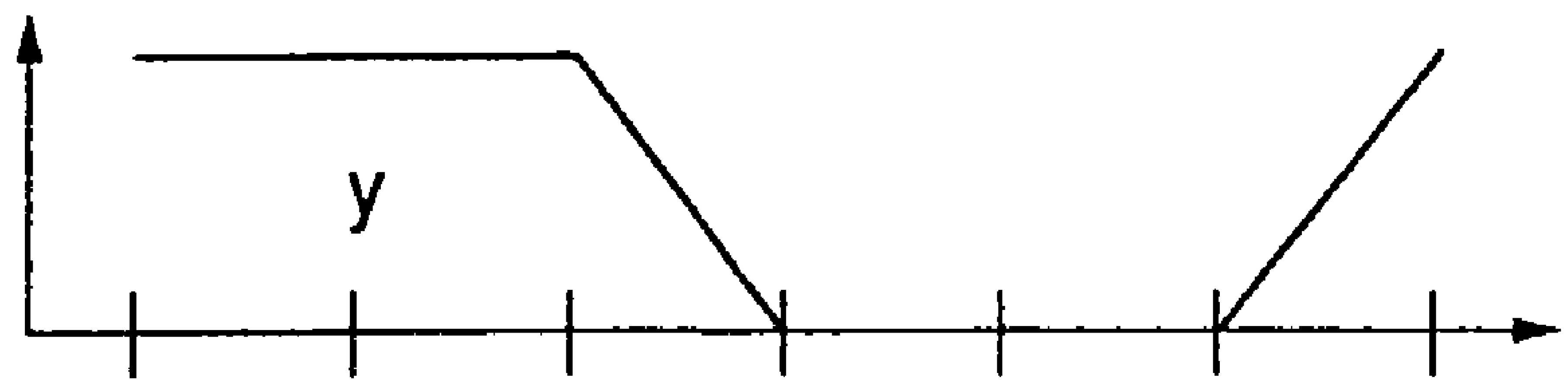


FIG. 6B

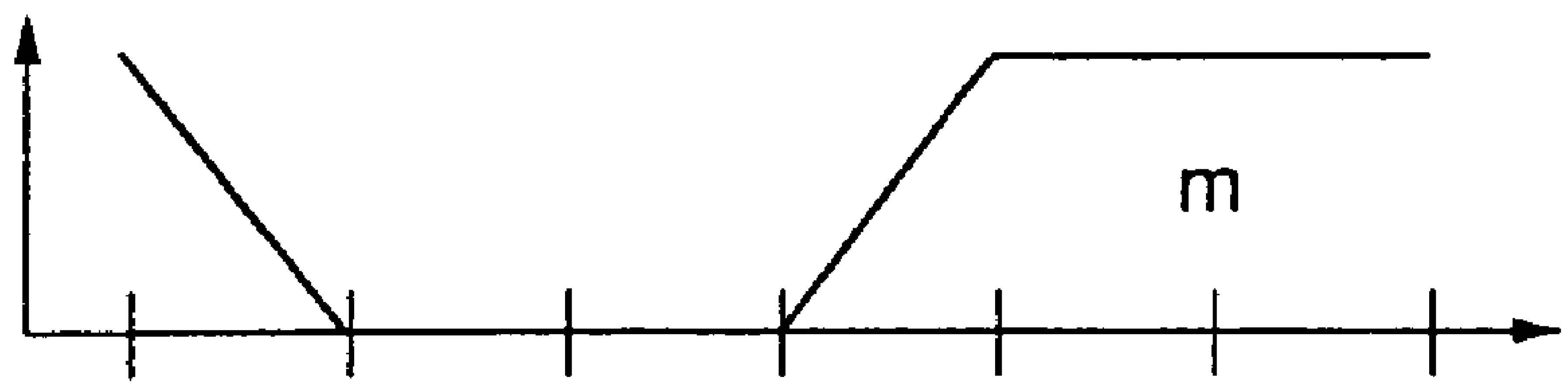


FIG. 6C

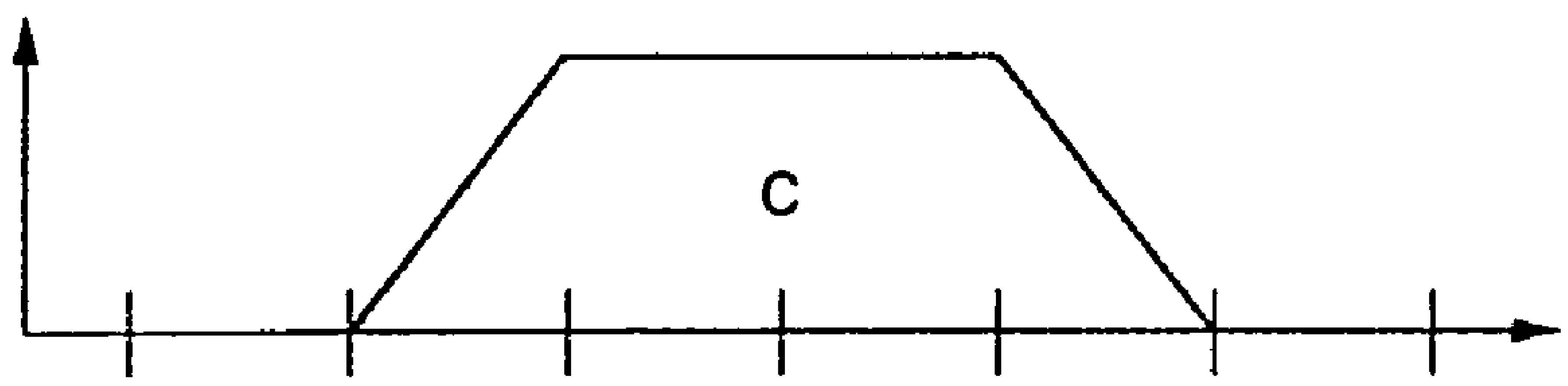


FIG. 6D

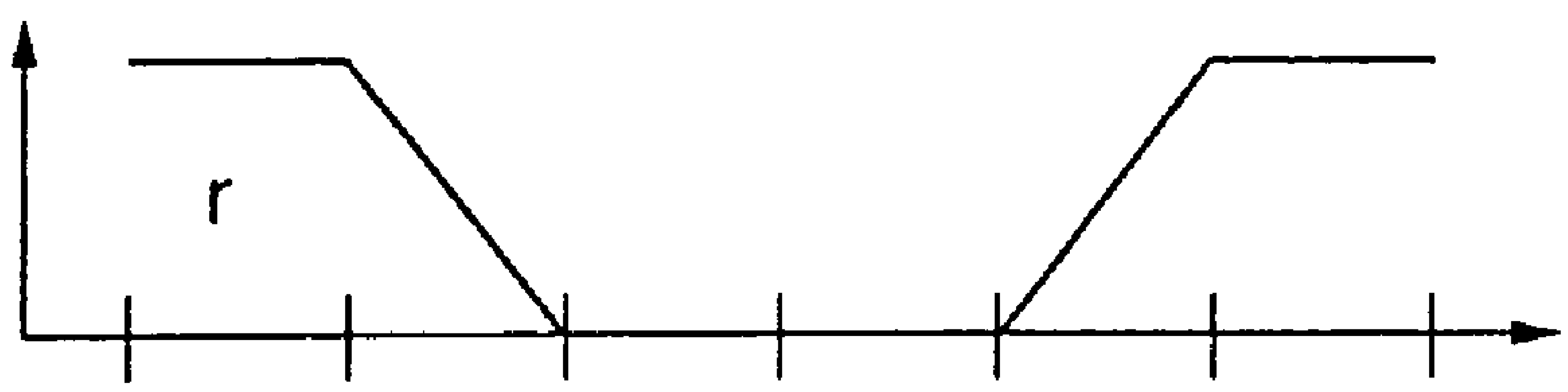


FIG. 6E

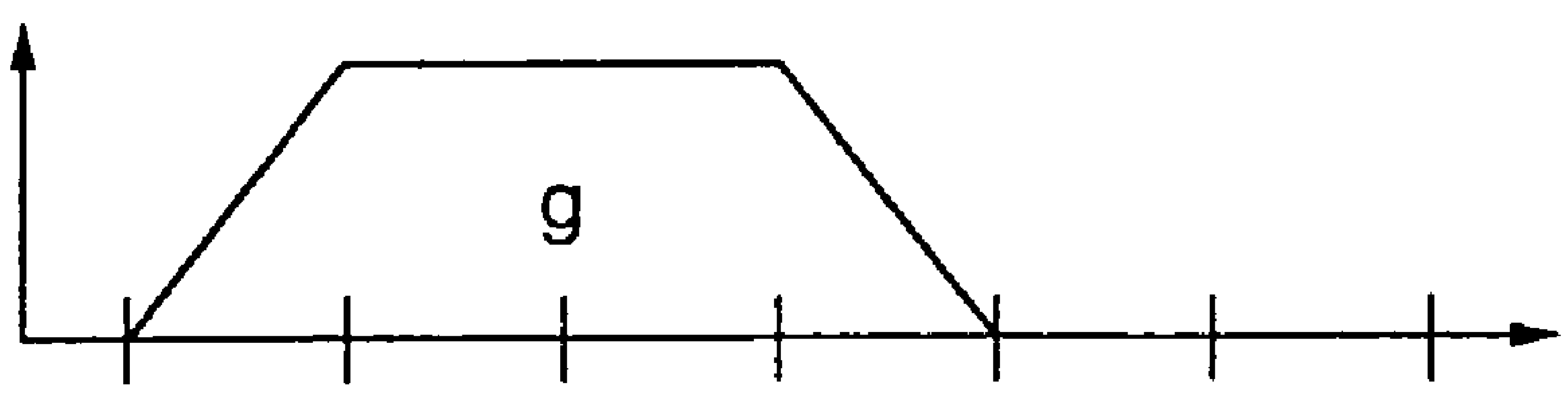


FIG. 6F

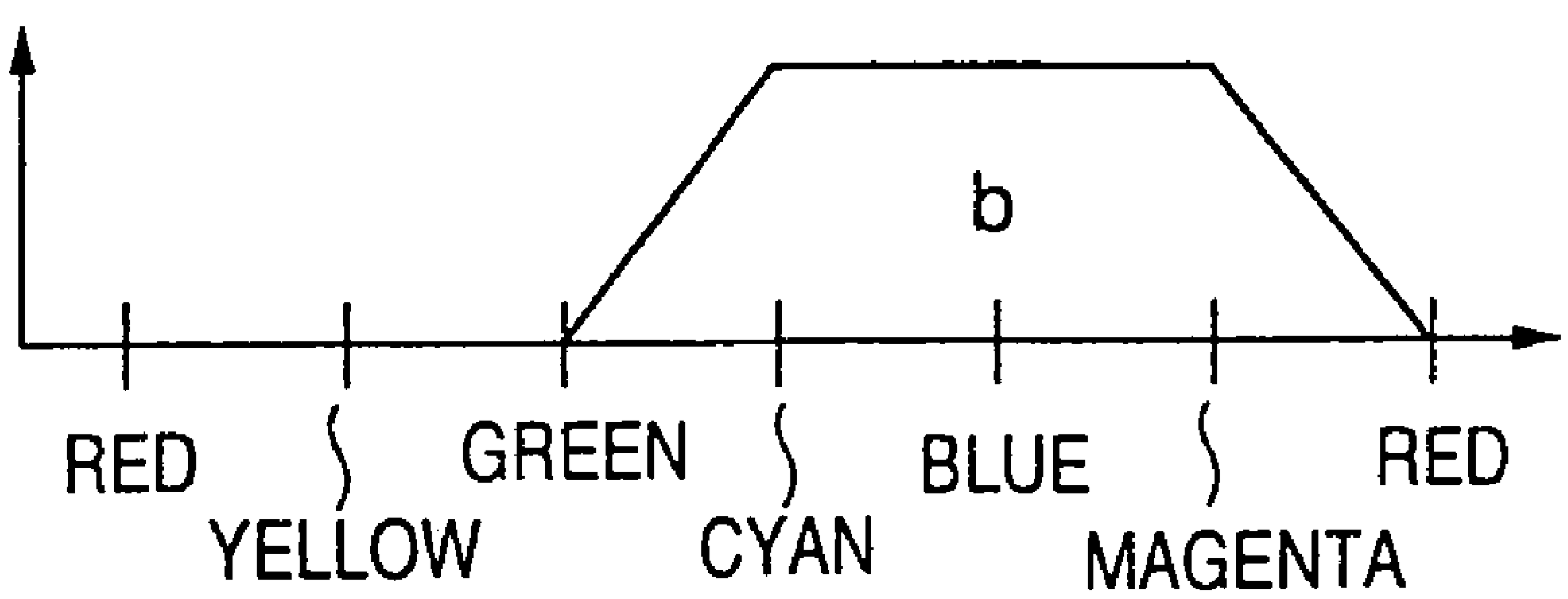


FIG. 7A

FIG. 7B

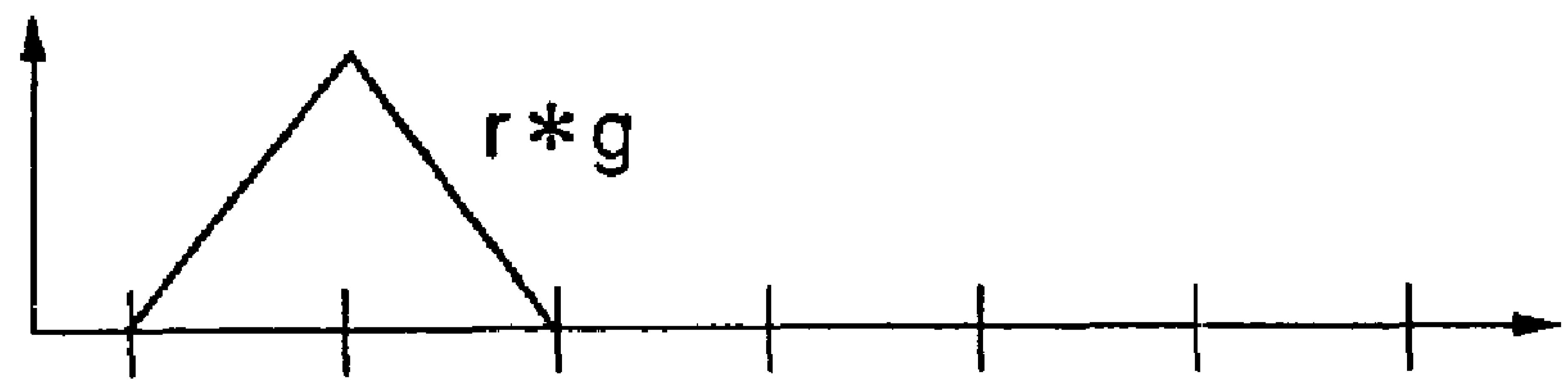


FIG. 7C

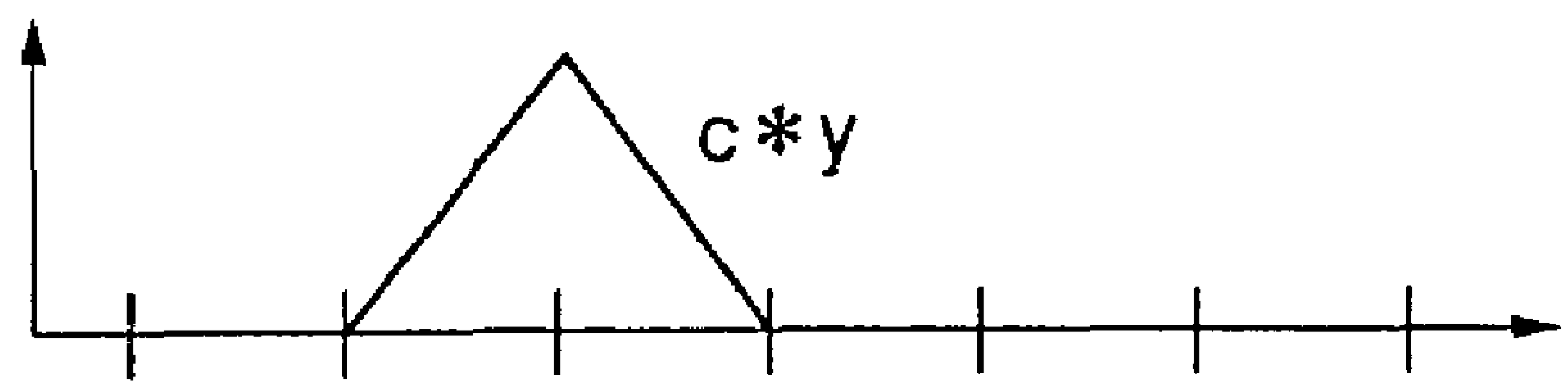


FIG. 7D

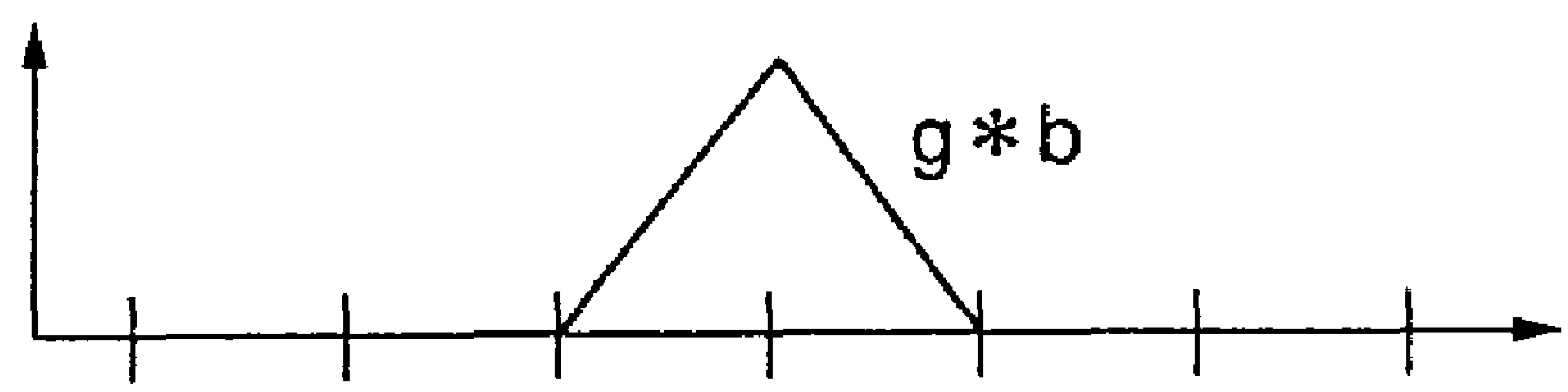


FIG. 7E

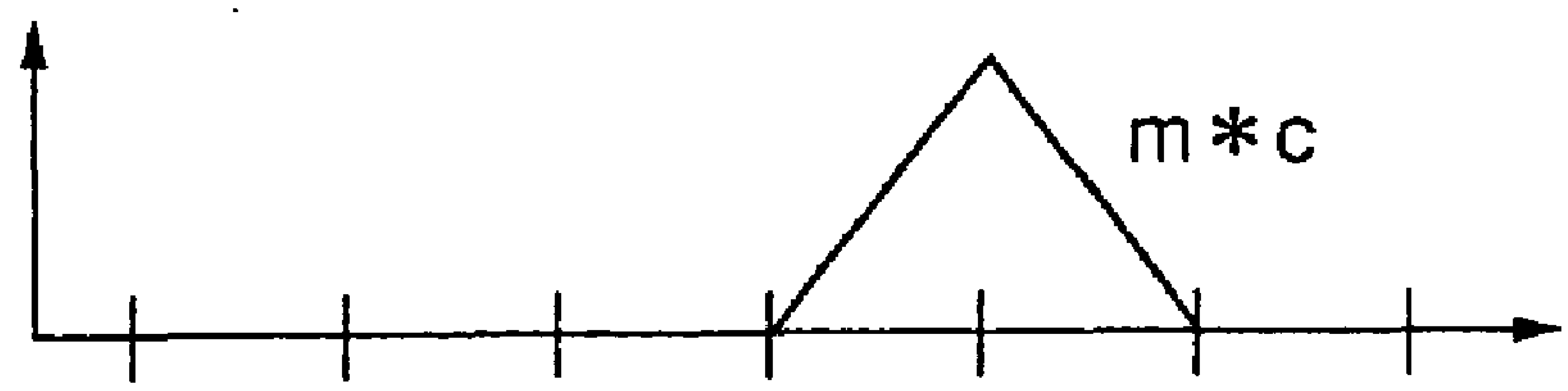


FIG. 7F

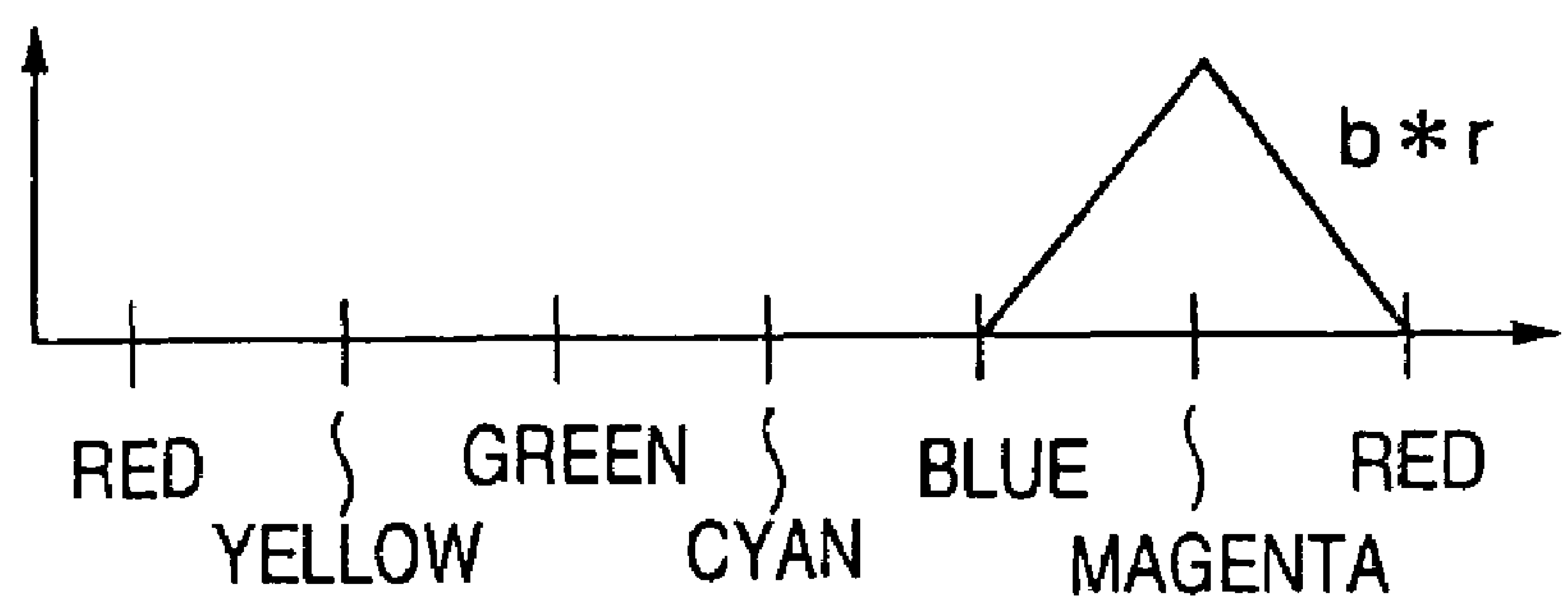


FIG. 8A

FIG. 8B

FIG. 8C

FIG. 8D

FIG. 8E

FIG. 8F

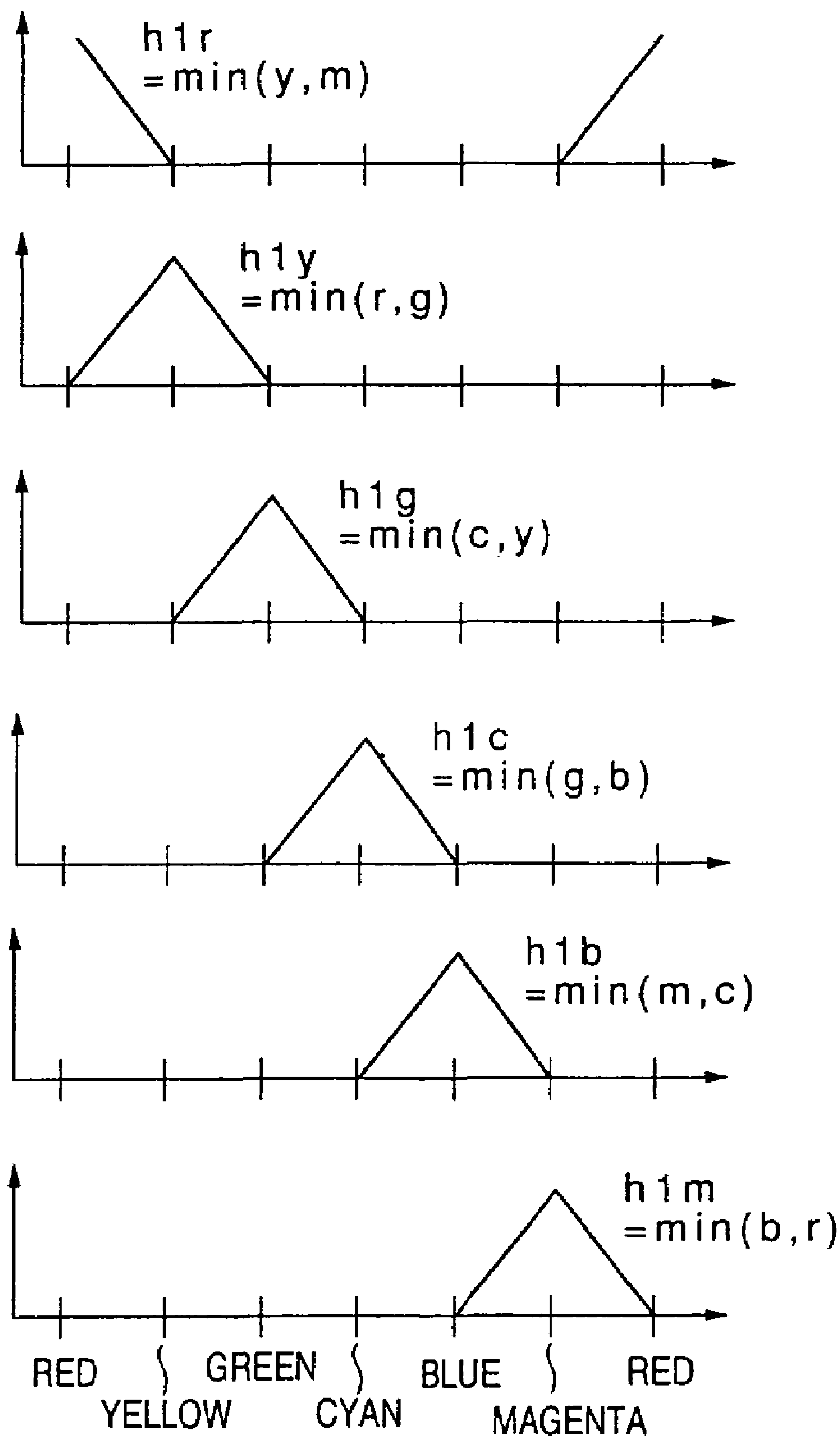


FIG. 9A

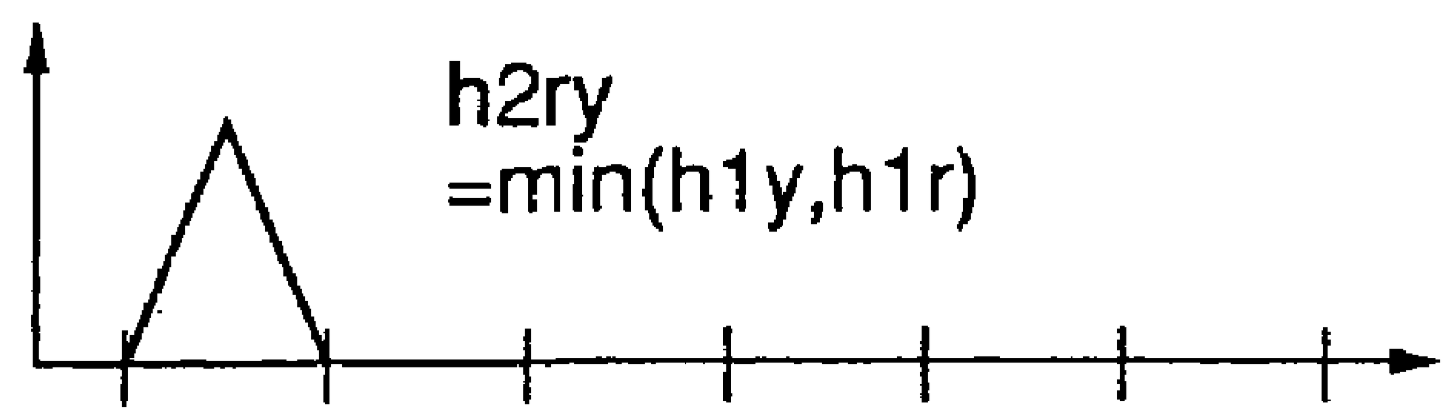


FIG. 9B

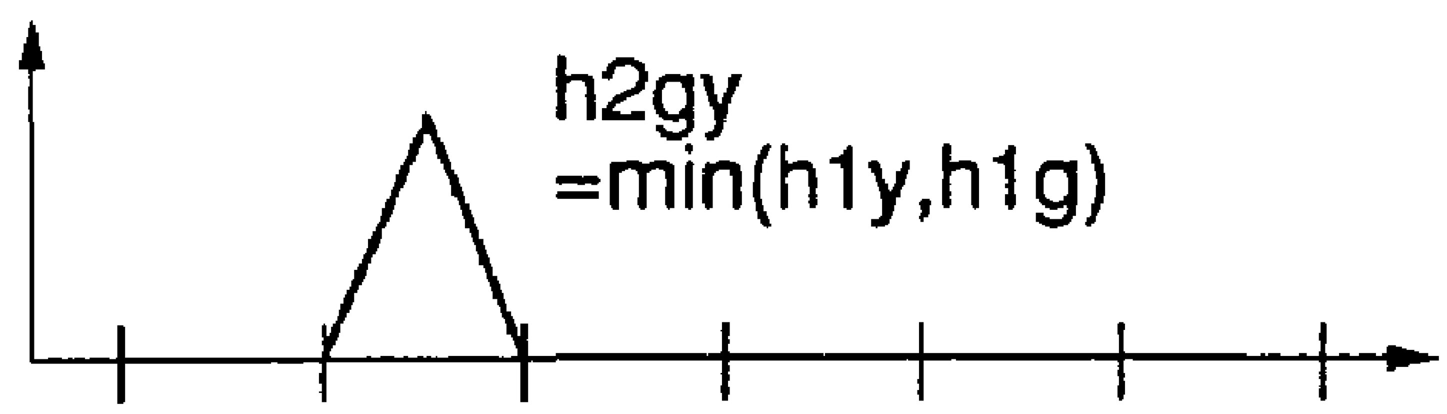


FIG. 9C

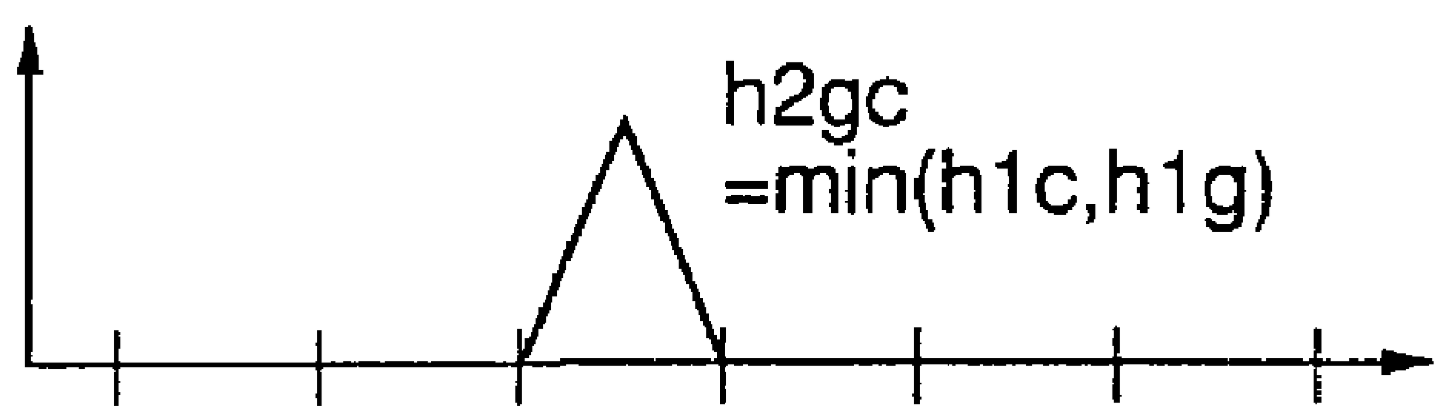


FIG. 9D

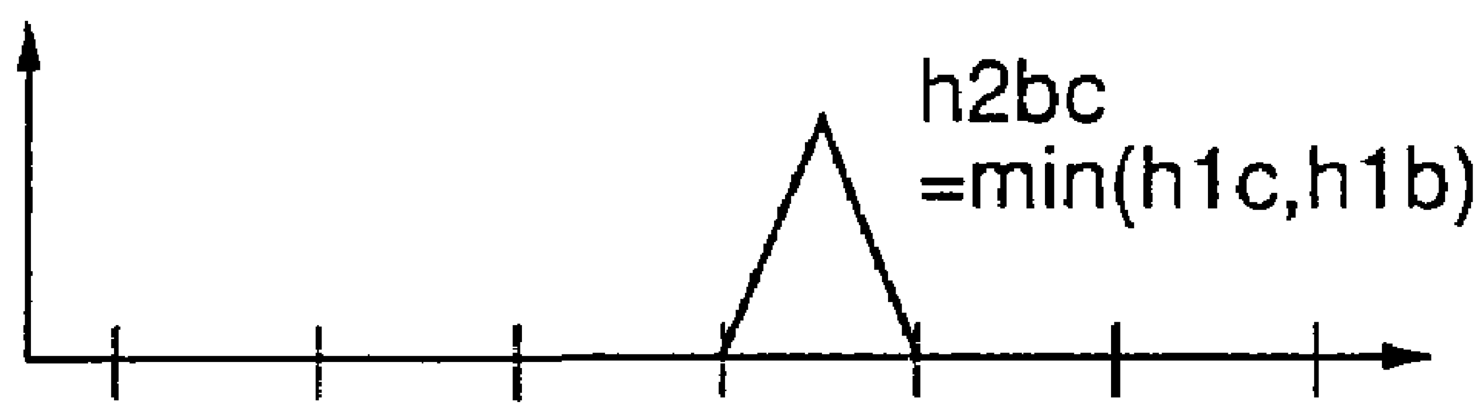


FIG. 9E

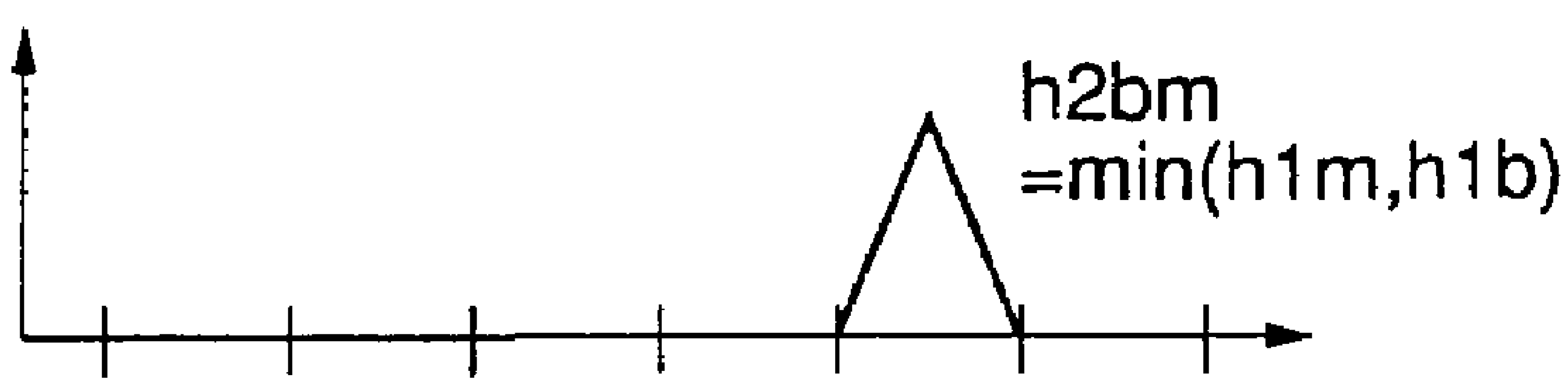


FIG. 9F

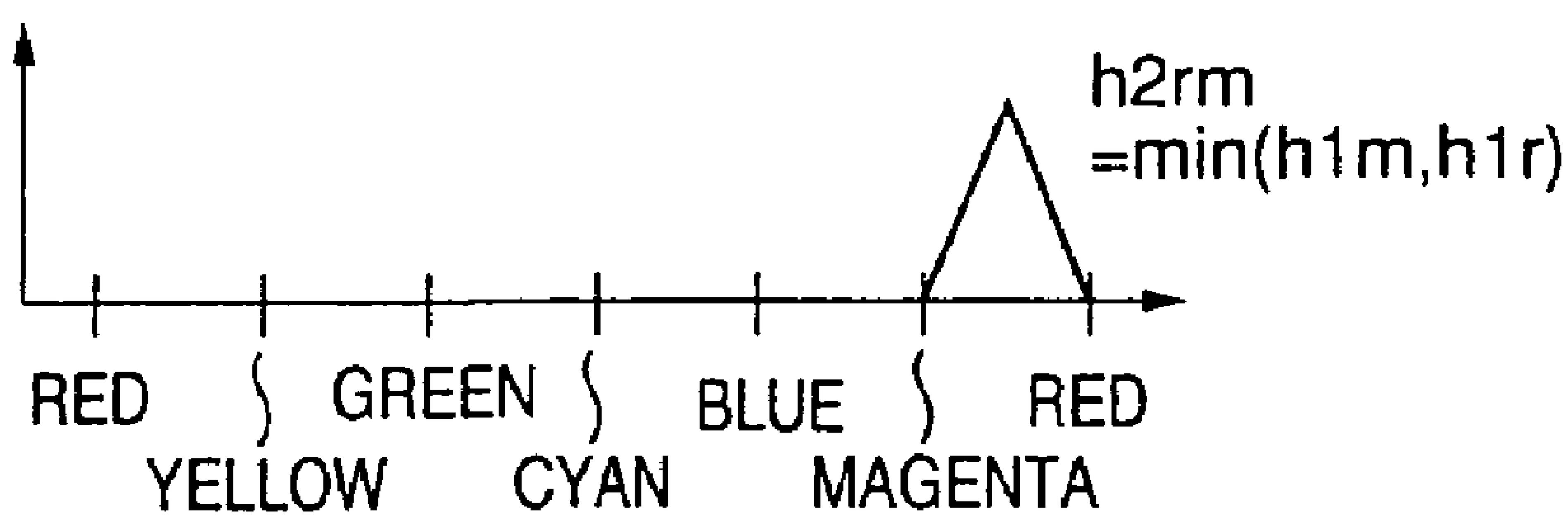


FIG. 10A
FIG. 10B
FIG. 10C
FIG. 10D
FIG. 10E
FIG. 10F

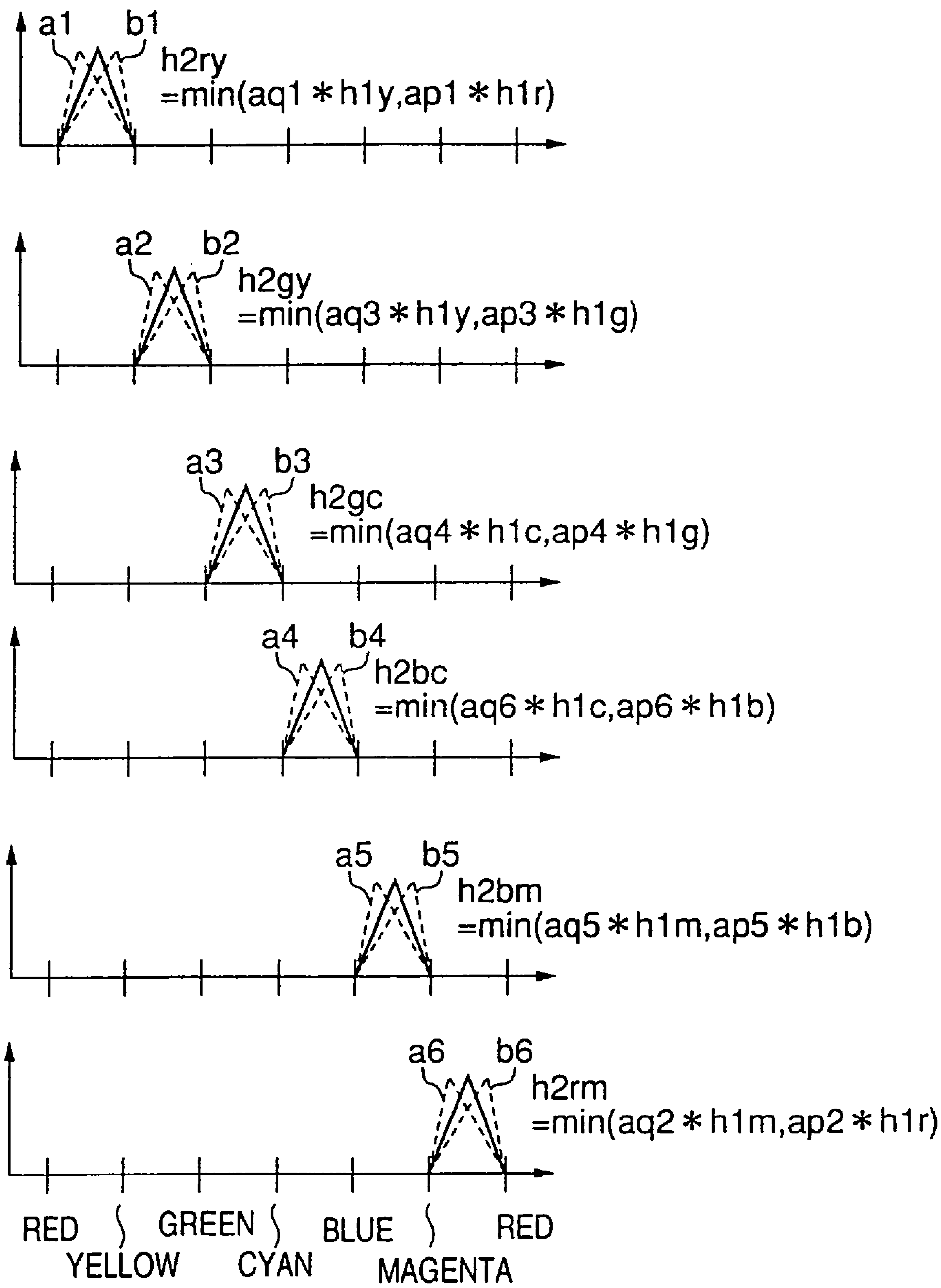


FIG. 11A

HUE	EFFECTIVE SECOND-ORDER TERM	EFFECTIVE FIRST COMPARISON-RESULT DATA
RED	mxy	h1r
GREEN	yxc	h1g
BLUE	cxm	h1b
CYAN	gxb	h1c
MAGENTA	bxr	h1m
YELLOW	rxg	h1y

FIG. 11B

INTER-HUE AREA	EFFECTIVE SECOND COMPARISON-RESULT DATA
RED-YELLOW	h2ry
YELLOW-GREEN	h2gy
GREEN-CYAN	h2gc
CYAN-BLUE	h2bc
BLUE-MAGENTA	h2bm
MAGENTA-RED	h2rm

FIG. 12

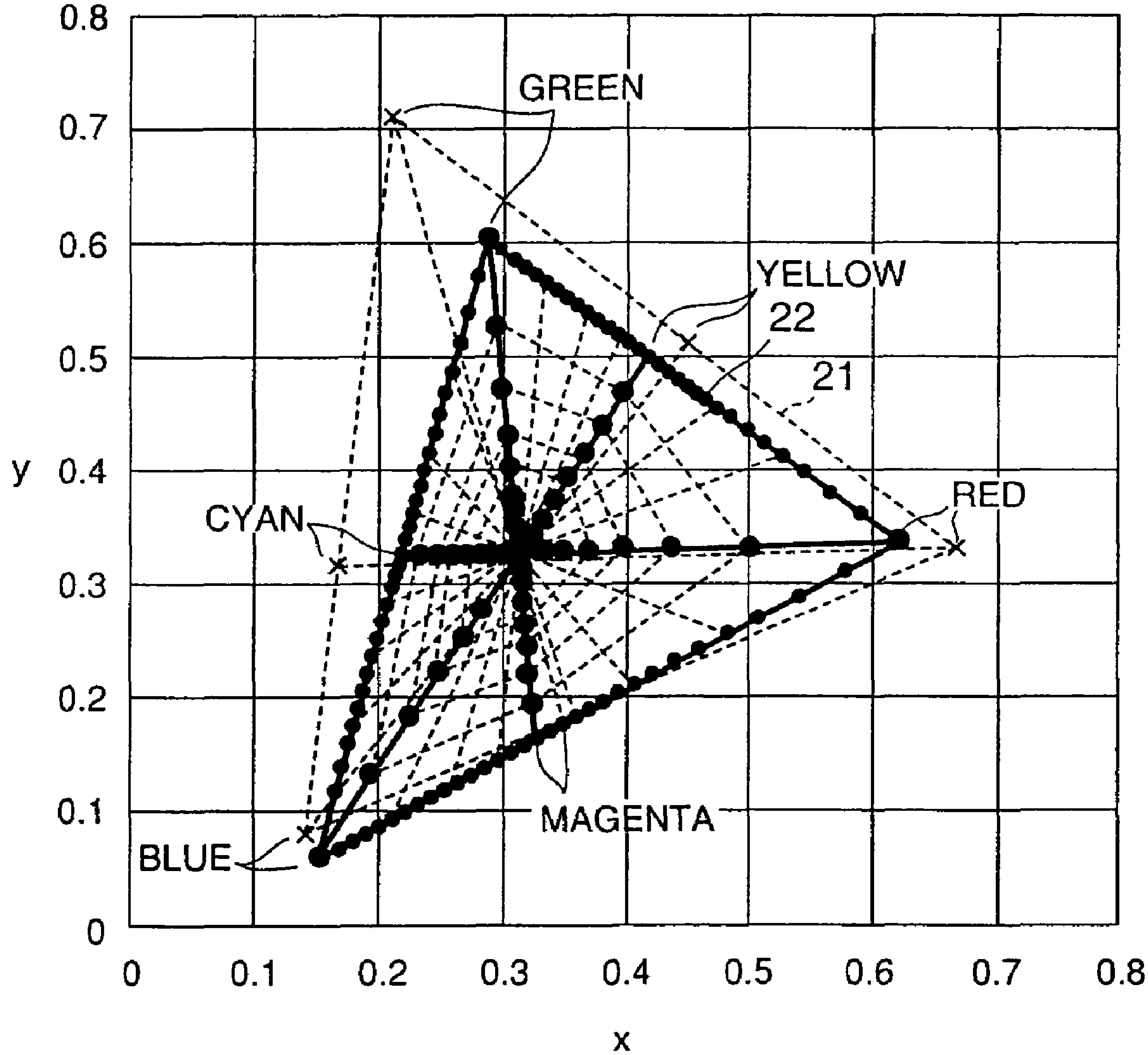

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
y
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x
GREEN
YELLOW
22
21
RED
CYAN
MAGENTA
BLUE

FIG. 13

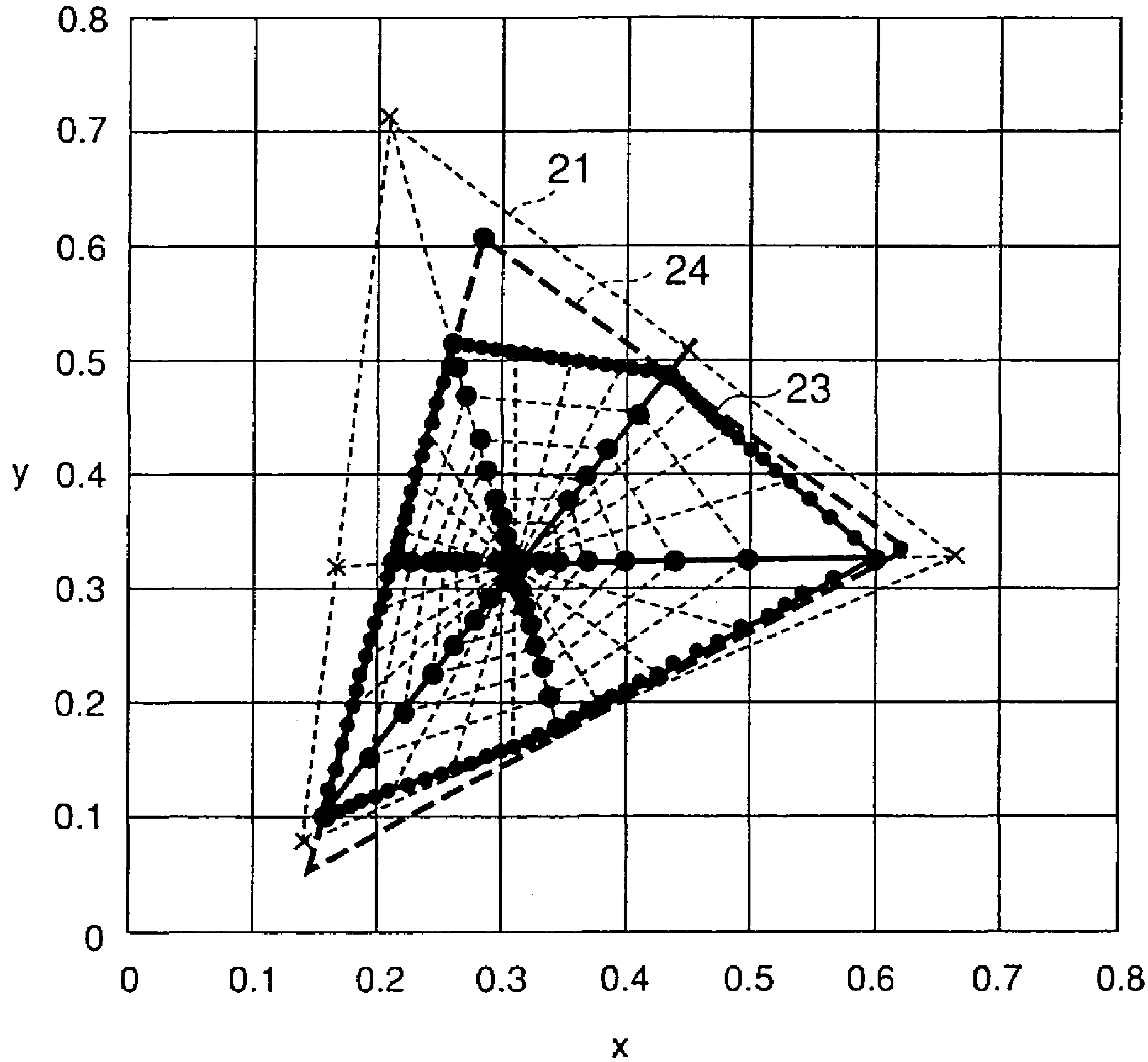


FIG. 14

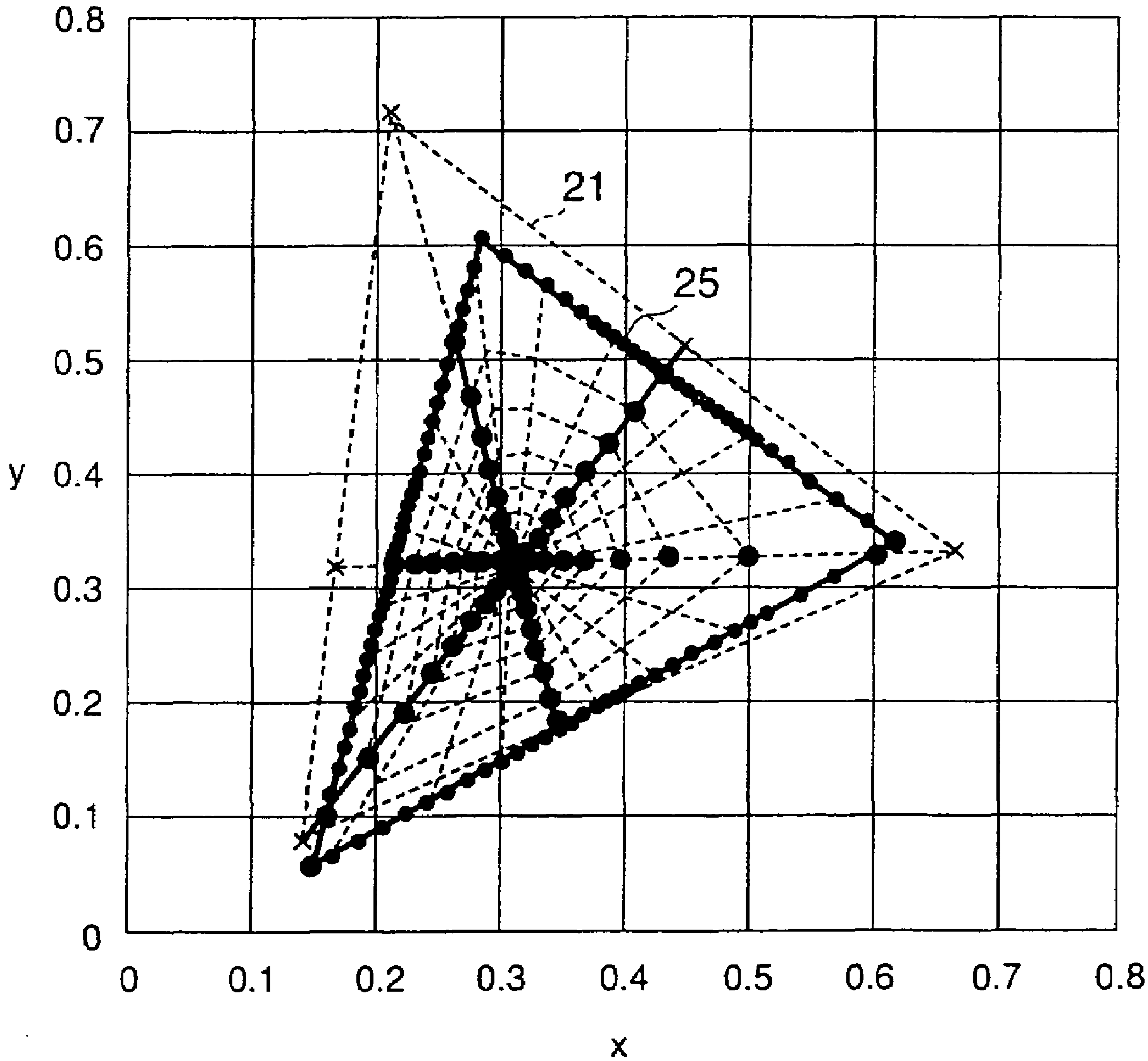
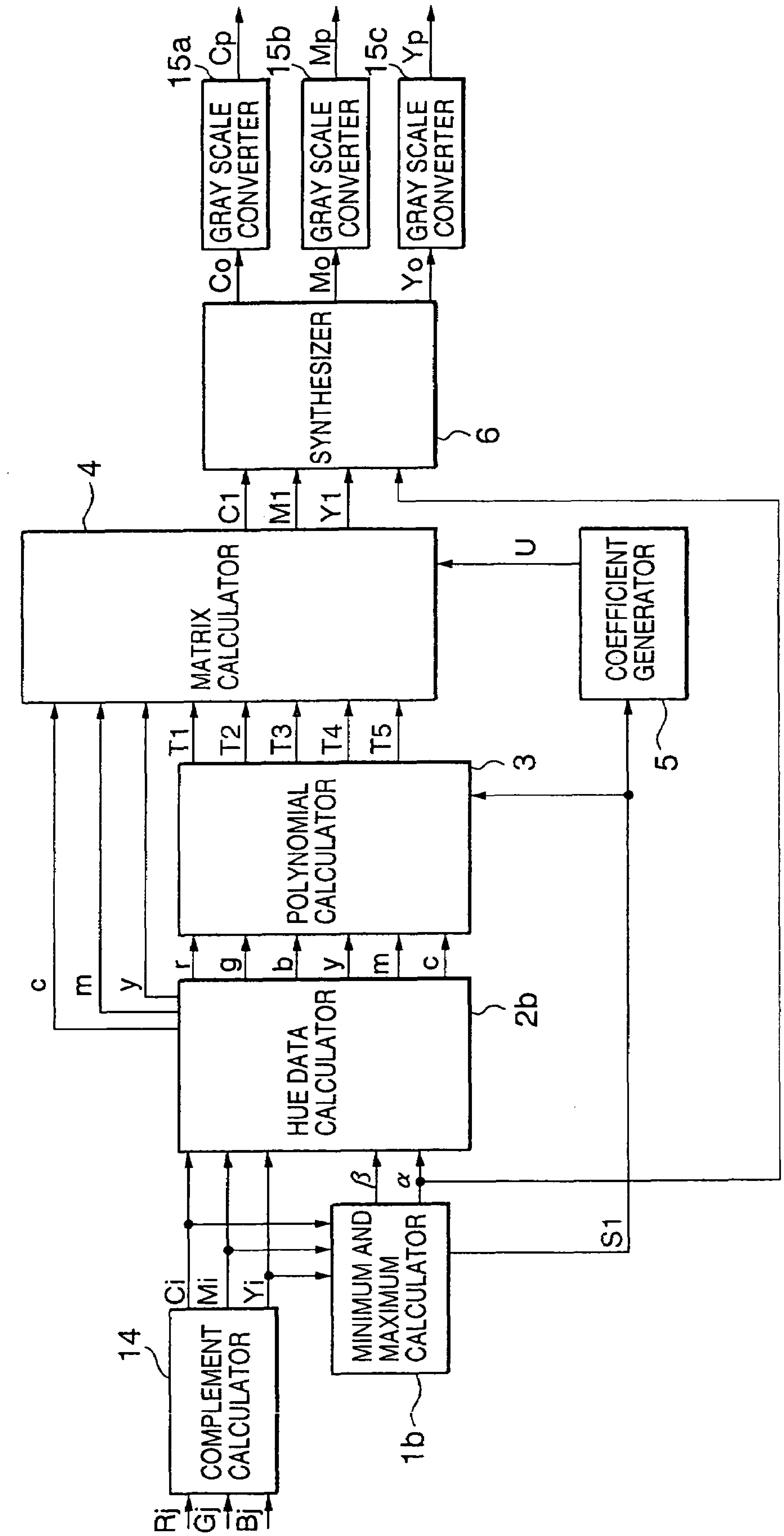


FIG. 15



Rj
Gj
Bj
COMPLEMENT CALCULATOR
14
Ci
Mi
Yi
MINIMUM AND MAXIMUM CALCULATOR
1b
β
α
S1
HUE DATA CALCULATOR
2b
c
m
y
r
g
b
y
m
c
POLYNOMIAL CALCULATOR
3
T1
T2
T3
T4
T5
MATRIX CALCULATOR
4
COEFFICIENT GENERATOR
5
U
C1
M1
Y1
SYNTHESIZER
6
Co
Mo
Yo
GRAY SCALE CONVERTER
GRAY SCALE CONVERTER
GRAY SCALE CONVERTER
15a
15b
15c
Cp
Mp
Yp

FIG. 16

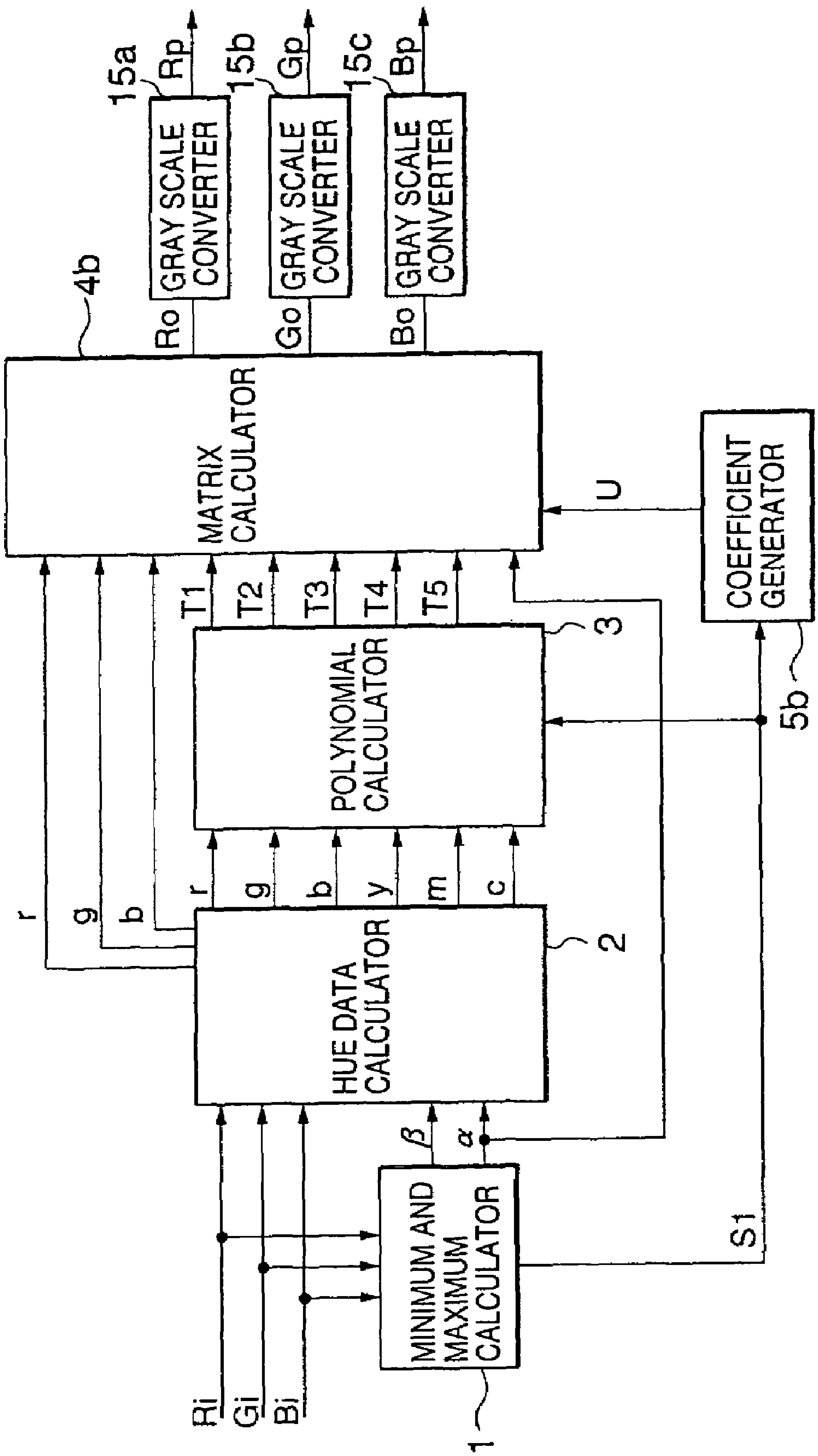

MINIMUM AND MAXIMUM CALCULATOR
HUE DATA CALCULATOR
POLYNOMIAL CALCULATOR
MATRIX CALCULATOR
COEFFICIENT GENERATOR
GRAY SCALE CONVERTER
GRAY SCALE CONVERTER
GRAY SCALE CONVERTER
Ri
Gi
Bi
1
2
3
4b
5b
15a
15b
15c
S1
α
β
r
g
b
y
m
c
T1
T2
T3
T4
T5
U
Ro
Go
Bo
Rp
Gp
Bp

FIG. 17

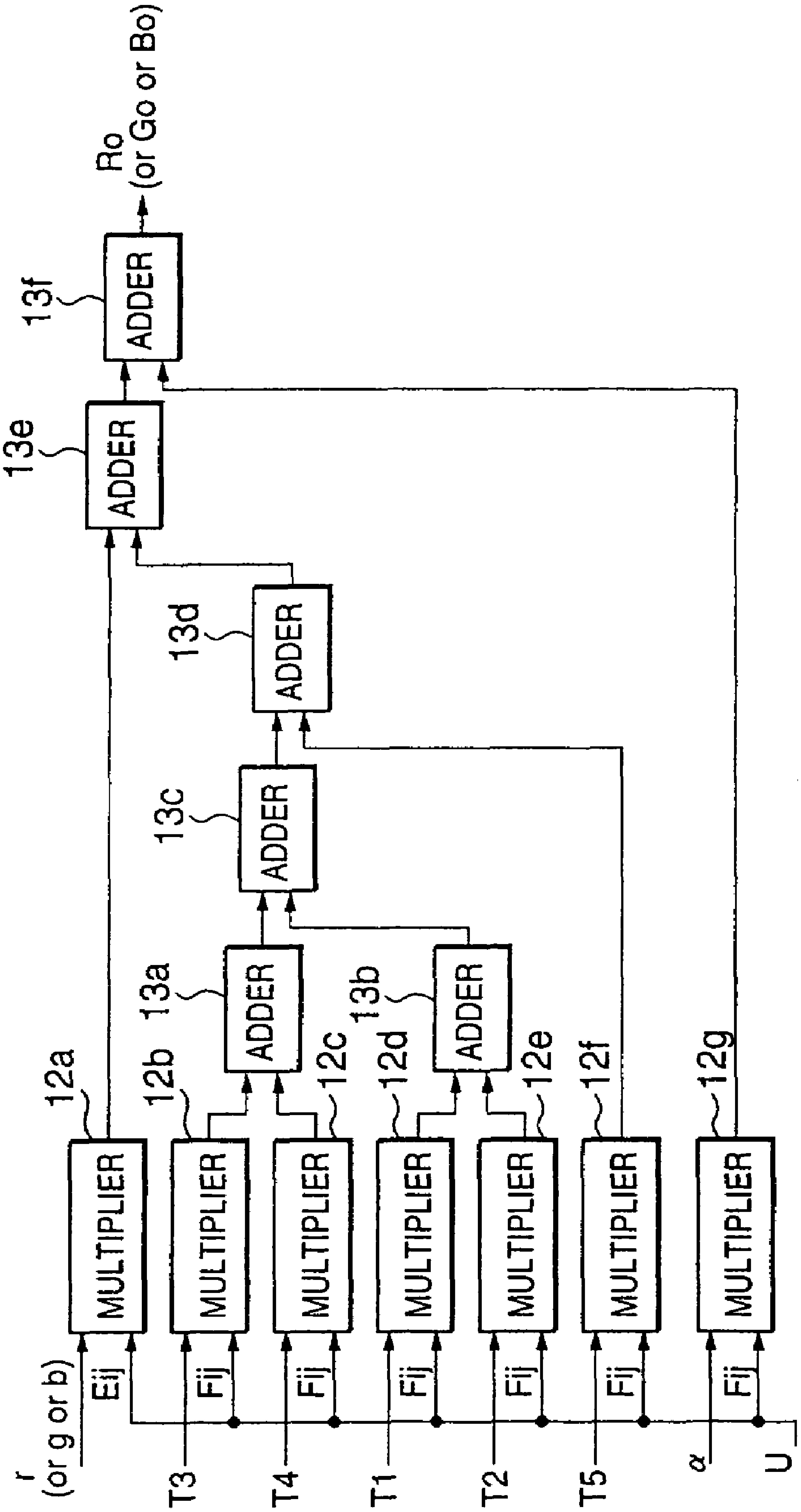

Ro
(or Go or Bo)
ADDER
13f
ADDER
13e
ADDER
13d
ADDER
13c
ADDER
13a
ADDER
13b
12a
12b
12c
12d
12e
12f
12g
MULTIPLIER
MULTIPLIER
MULTIPLIER
MULTIPLIER
MULTIPLIER
MULTIPLIER
MULTIPLIER
r
(or g or b)
Eij
Fij
T3
T4
T1
T2
T5
α
U

FIG. 18

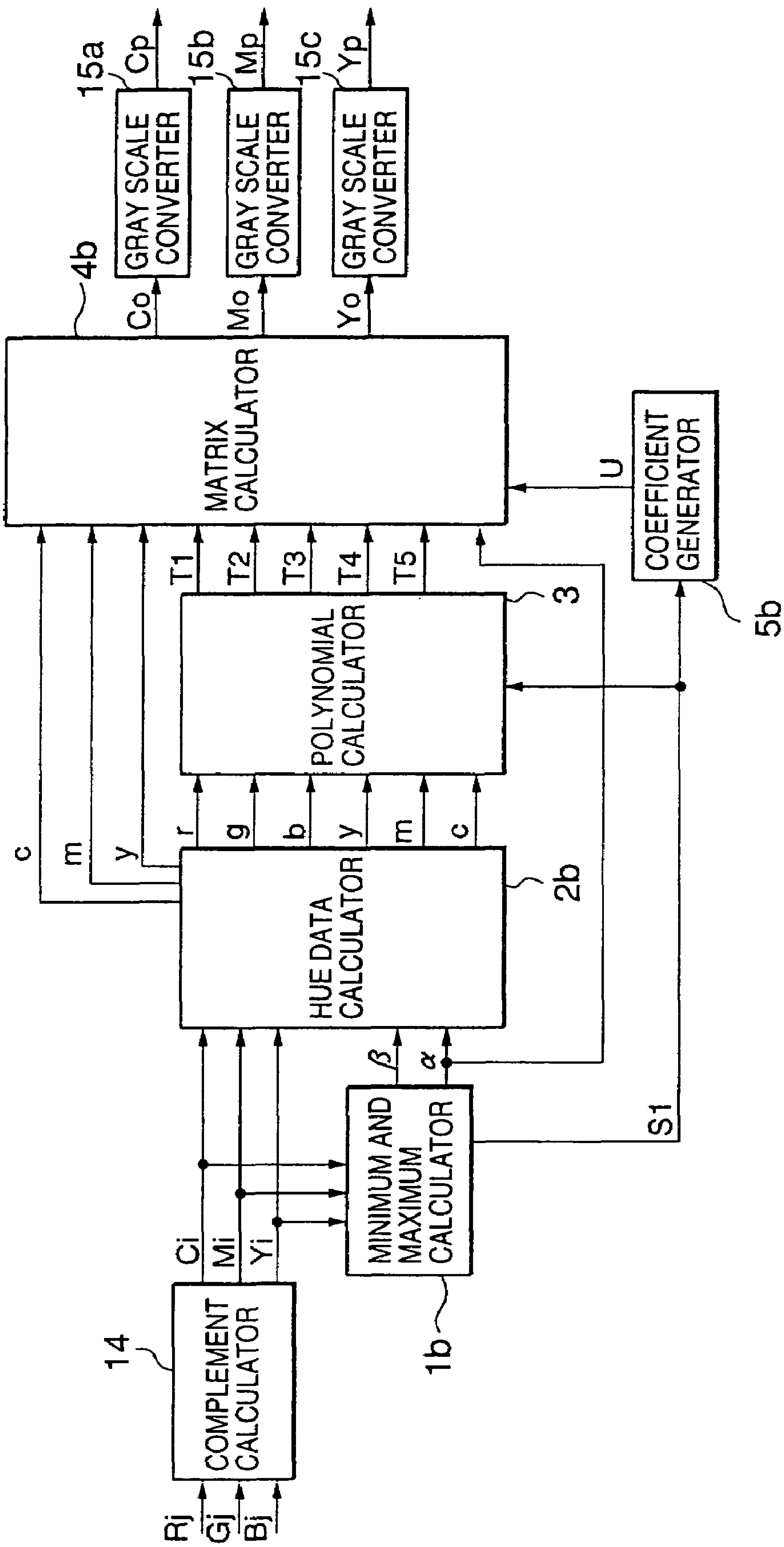

Rj
Gj
Bj
COMPLEMENT CALCULATOR
14
Ci
Mi
Yi
MINIMUM AND MAXIMUM CALCULATOR
1b
β
α
S1
HUE DATA CALCULATOR
2b
c
m
y
r
g
b
y
m
c
POLYNOMIAL CALCULATOR
3
T1
T2
T3
T4
T5
COEFFICIENT GENERATOR
5b
U
MATRIX CALCULATOR
4b
Co
Mo
Yo
GRAY SCALE CONVERTER
15a
Cp
GRAY SCALE CONVERTER
15b
Mp
GRAY SCALE CONVERTER
15c
Yp

FIG. 19

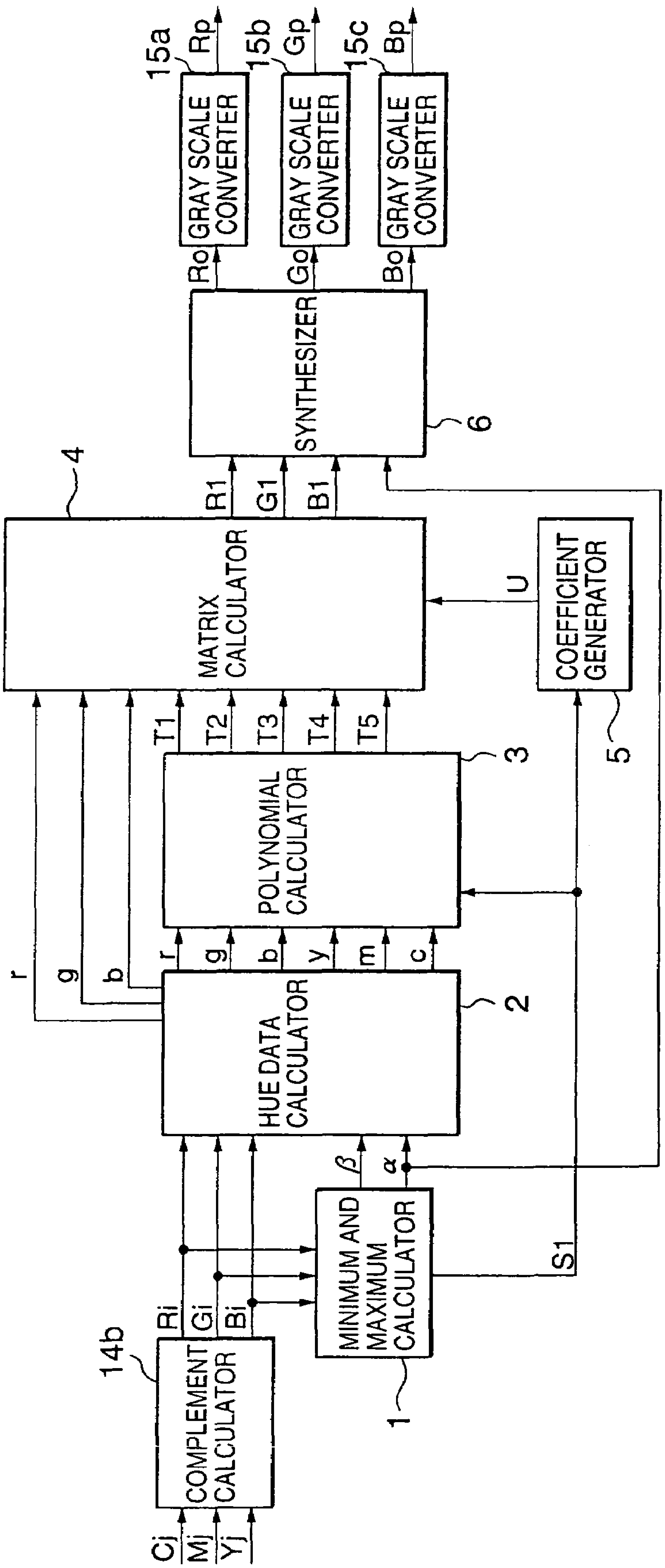

Cj
Mj
Yj
COMPLEMENT CALCULATOR
14b
Ri
Gi
Bi
MINIMUM AND MAXIMUM CALCULATOR
1
S1
β
α
HUE DATA CALCULATOR
2
r
g
b
y
m
c
POLYNOMIAL CALCULATOR
3
T1
T2
T3
T4
T5
MATRIX CALCULATOR
4
U
COEFFICIENT GENERATOR
5
R1
G1
B1
SYNTHESIZER
6
Ro
Go
Bo
GRAY SCALE CONVERTER
15a
15b
15c
Rp
Gp
Bp

FIG. 20
PRIOR ART

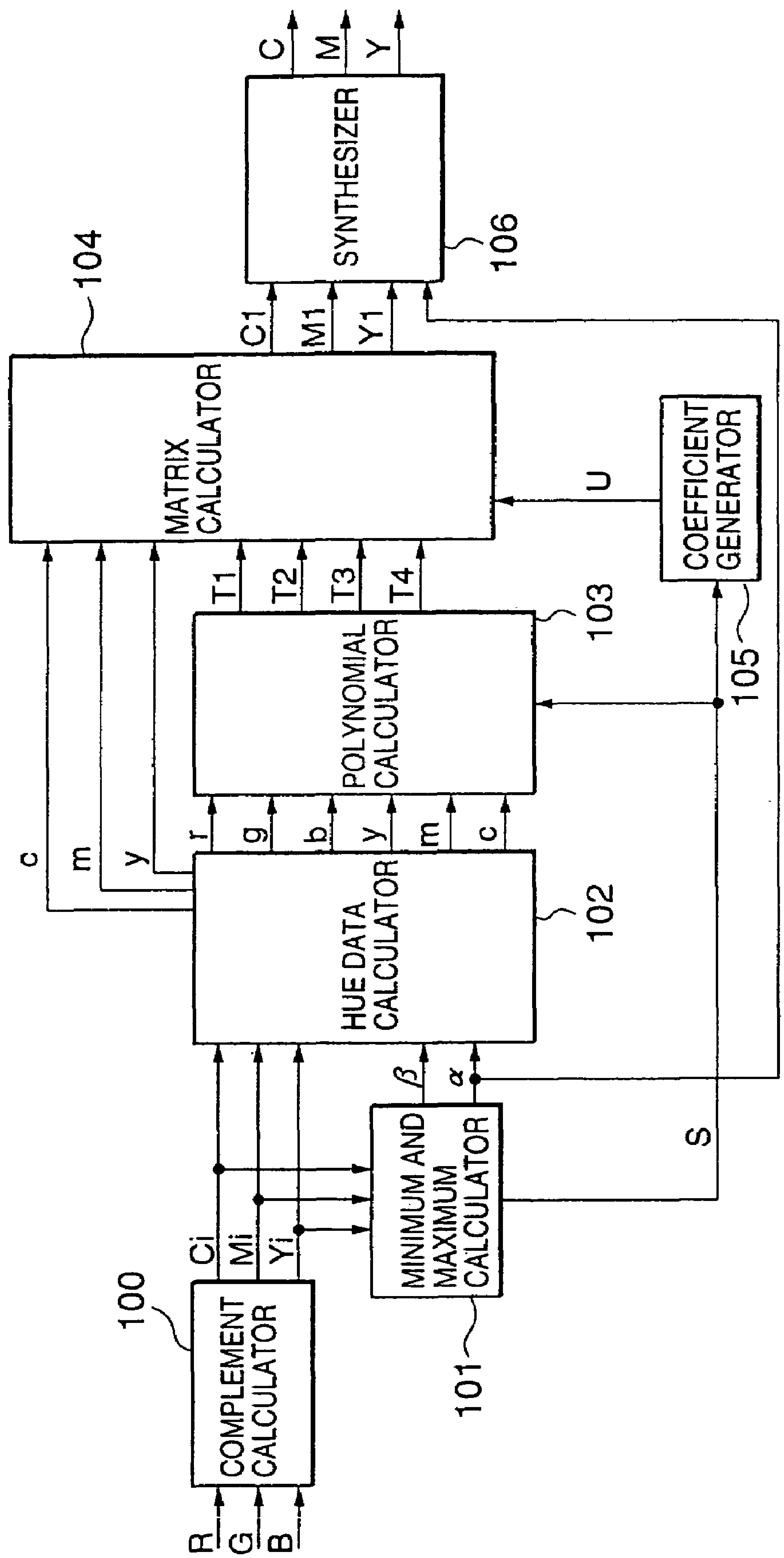


FIG. 21A
PRIOR ART

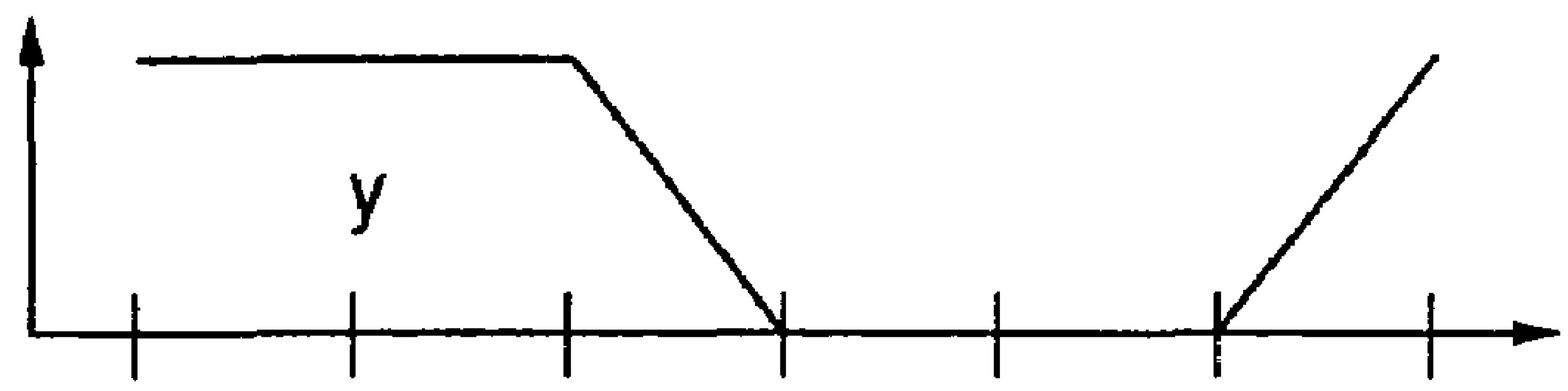


FIG. 21B
PRIOR ART

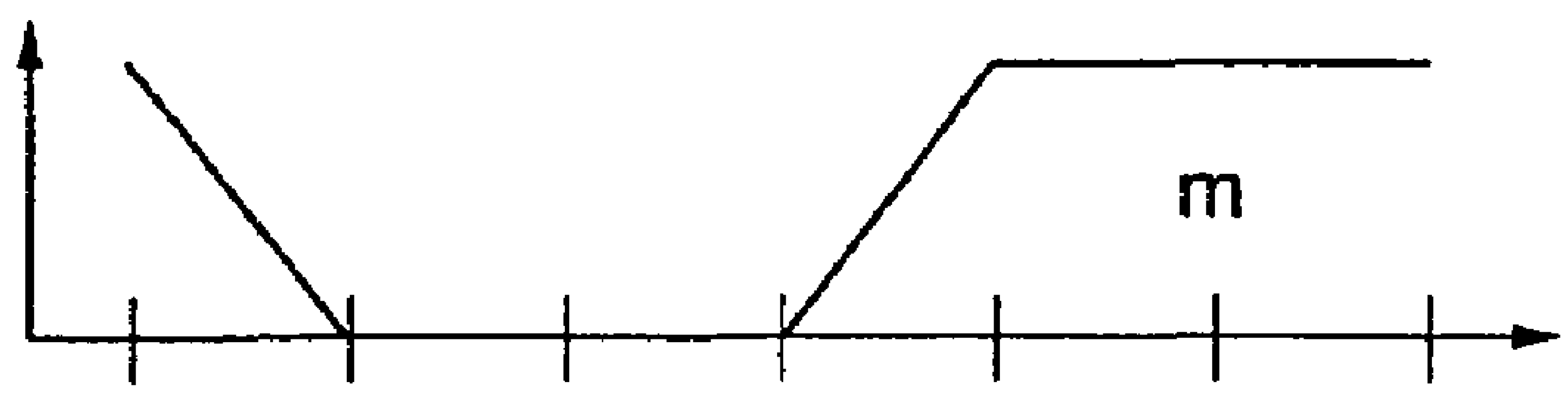


FIG. 21C
PRIOR ART

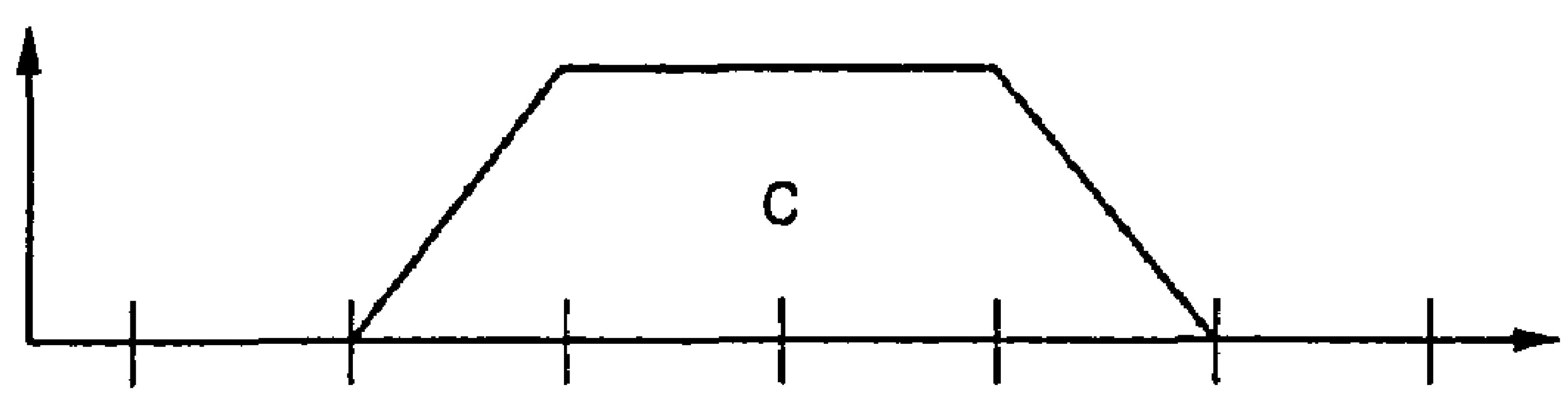


FIG. 21D
PRIOR ART

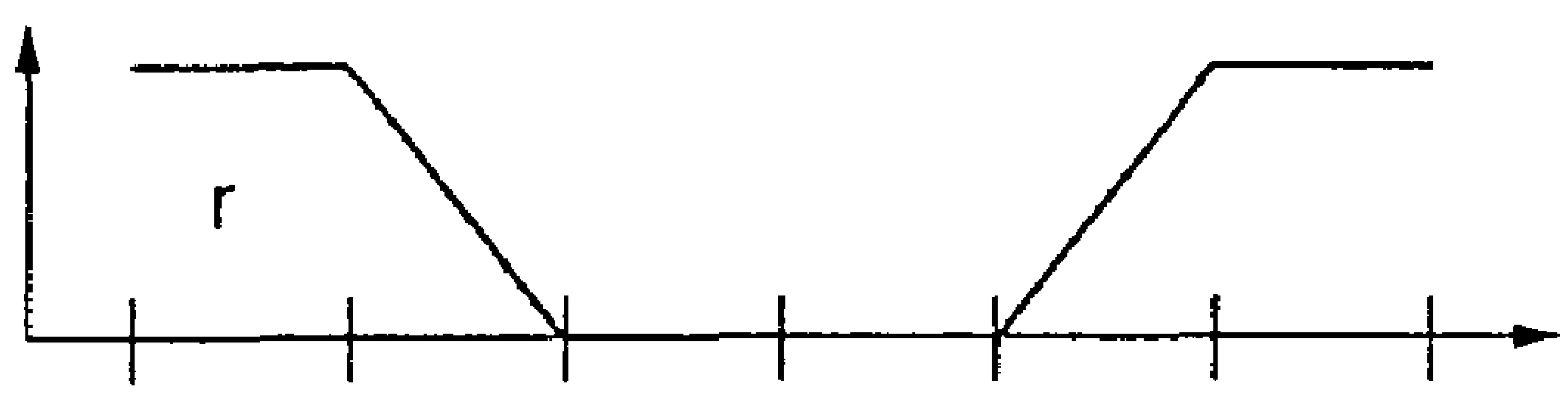


FIG. 21E
PRIOR ART

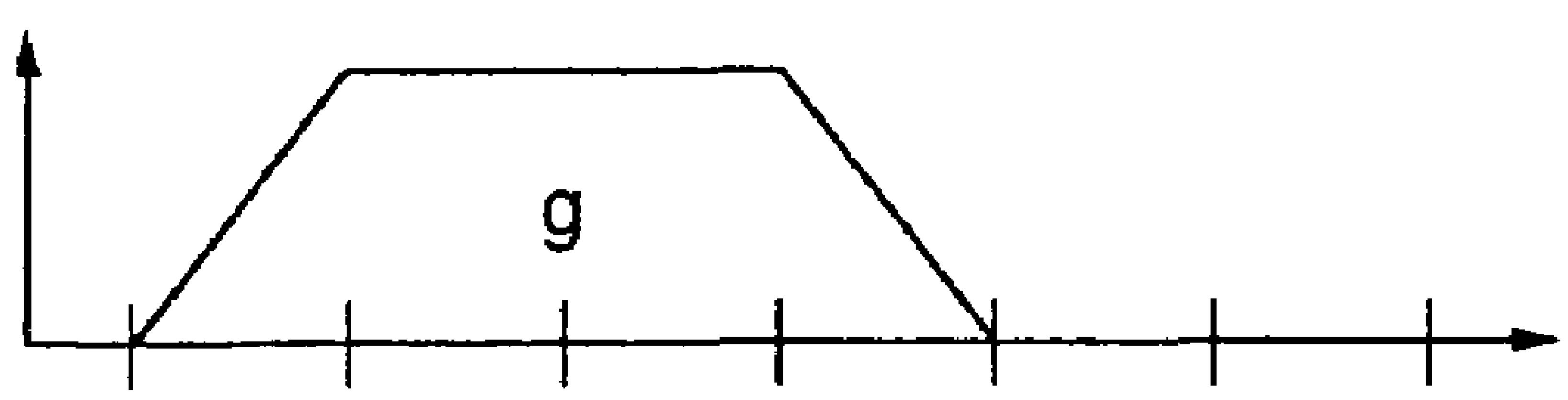


FIG. 21F
PRIOR ART

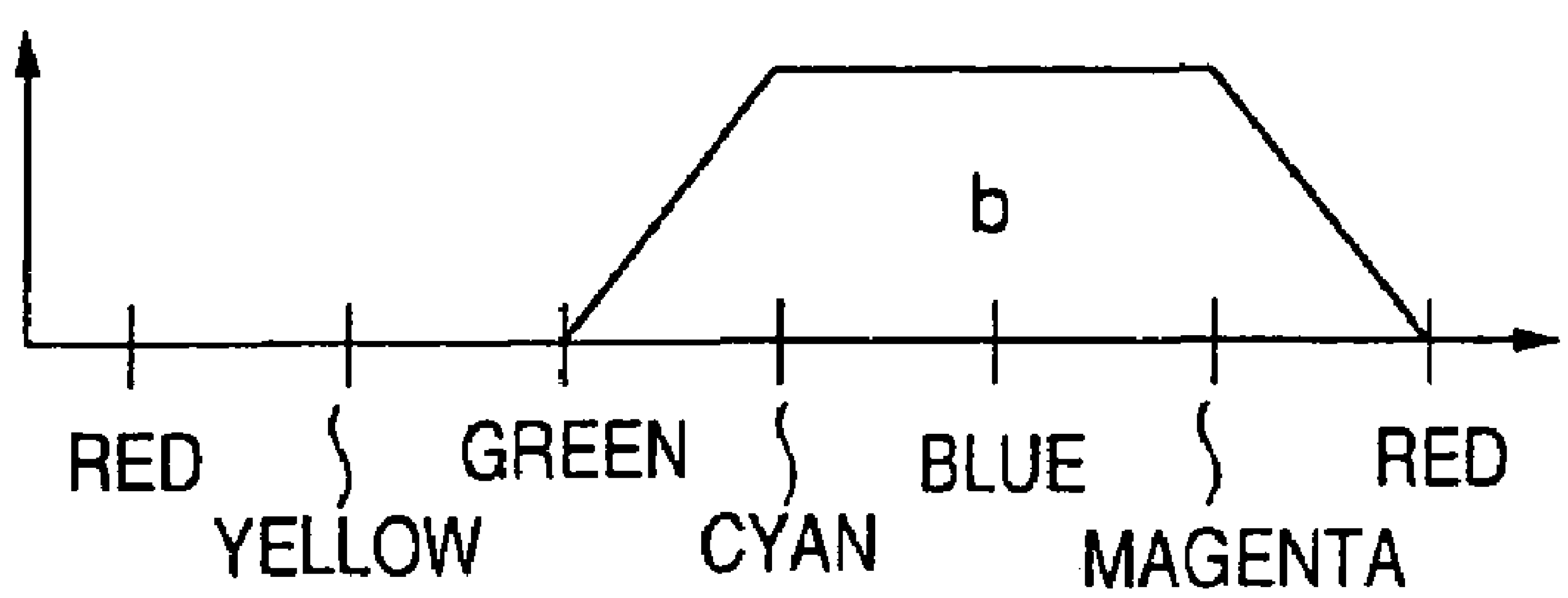


FIG. 22A
PRIOR ART

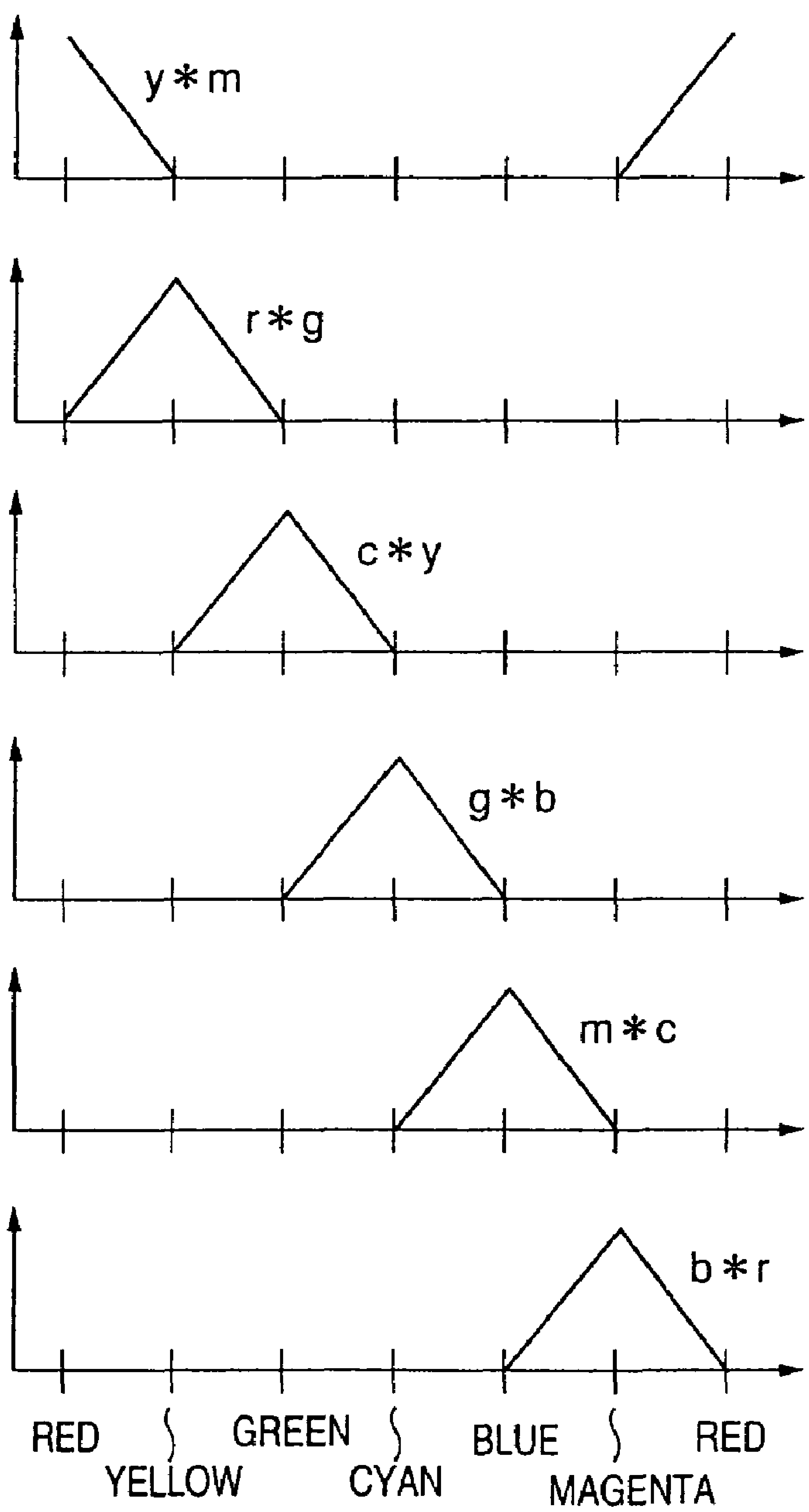
FIG. 22B
PRIOR ART

FIG. 22C
PRIOR ART

FIG. 22D
PRIOR ART

FIG. 22E
PRIOR ART

FIG. 22F
PRIOR ART



COLOR CONVERSION DEVICE AND COLOR CONVERSION METHOD

This application is a Divisional of co-pending application Ser. No. 09/689,645, filed on Oct. 13, 2000, and for which priority is claimed under 35 U.S.C. § 120; and this application claims priority of application Ser. No. 291893/99 filed in Japan on Oct. 14, 1999 under 35 U.S.C. § 119; the entire contents of all are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The present invention relates to data processing used for a full-color printing related equipment such as a printer, a video printer, a scanner or the like, an image processor for forming computer graphic images or a display device such as a monitor. More specifically, the invention relates to a color conversion device and a color conversion method for performing color conversion from image data in the form of a first set of three color data of red, green and blue, or cyan, magenta and yellow, to a second set of three color data of red, green and blue, or cyan, magenta and yellow.

Color conversion in printing is an indispensable technology for compensating deterioration of image quality due to color mixing property due to the fact that the ink is not of a pure color, or the non-linearity (in the hue) of the image-printing, and to output a printed image with a high color reproducibility. Also, in a display device such as a monitor or the like, color conversion is performed in order to output (display) an image having desired color reproducibility in accordance with conditions under which the device is used or the like when an inputted color signal is to be displayed.

Conventionally, two methods have been available for the foregoing color conversion: a table conversion method and a matrix calculation method.

A representative example of the table conversion method is a three-dimensional look-up table method, in which the image data represented by red, green and blue (hereinafter referred to as R, G, and B) are input, to output an image data of R, G, and B stored in advance in a memory, such as a ROM, or complementary color data of yellow, cyan and magenta (hereinafter referred to as Y, M, and C). Because any desired conversion characteristics can be achieved, color conversion with a good color reproducibility can be performed.

However, in a simple structure for storing data for each combination of image data, a large-capacity memory of about 400 Mbites must be used. For example, even in the case of a compression method for memory capacity disclosed in Japanese Patent Kokai Publication No. S63-227181, memory capacity is about 5 Mbites. Therefore, a problem inherent in the table conversion system is that since a large-capacity memory is necessary for each conversion characteristic, it is difficult to implement the method by means of an LSI, and it is also impossible to deal with changes in the condition under which the conversion is carried out.

On the other hand, in the case of the matrix calculation method, for example, for obtaining printing data of Y, M and C from image data of R, G and B, the following formula (11) is used as a basic calculation formula.

$$\begin{bmatrix} Y \\ M \\ C \end{bmatrix} = (Aij)\begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{11}$$

Here, Aij represents coefficients, with i=1 to 3, and j=1 to 3.

However, by the simple linear calculation of the formula (11), it is impossible to provide a good conversion characteristic because of a non-linearity of an image-printing or the like.

A method has been proposed for providing a conversion characteristic to improve the foregoing characteristic. This method is disclosed in Japanese Patent Application Kokoku Publication H2-30226, directed to a color correction calculation device, and employs a matrix calculation formula (12) below.

$$\begin{bmatrix} Y \\ M \\ C \end{bmatrix} = (Dij)\begin{bmatrix} R \\ G \\ B \\ R*G \\ G*B \\ B*R \\ R*R \\ G*G \\ B*B \\ N \end{bmatrix} \tag{12}$$

Here, N is a constant, i=1 to 3, and J=1 to 10.

In the foregoing formula (12), since image data having a mixture of an achromatic component and a color component is directly used, mutual interference occur in computation. In other words, if one of the coefficients is changed, influence is given to the components or hues other than the target component or hue (the component or hue for which the coefficient is changed). Consequently, a good conversion characteristic cannot be realized.

A color conversion method disclosed in Japanese Patent Application Kokai Publication H7-170404 is a proposed solution to this problem. FIG. **20** is a block circuit diagram showing the color conversion method for conversion of image data of R, G and B into printing data of C, M and Y, disclosed in Japanese Patent Application Kokai Publication H7-170404. In the drawing, reference numeral **100** denotes a complement calculator; **101**, a minimum and maximum calculator; **102**, a hue data calculator; **103**, a polynomial calculator; **104**, a matrix calculator; **105**, a coefficient generator; and **106**, a synthesizer.

Next, the operation will be described. The complement calculator **100** receives image data R, G and B, and outputs complementary color data Ci, Mi and Yi which have been obtained by determining 1's complements.

The determination of 1's complement of an input data can be achieved by subtracting the value of the input data of n bits (n being an integer) from (2^n-1). For example, in the case of 8-bit data, the value of the input data is deducted from "255".

The minimum and maximum calculator **101** outputs a maximum value β and a minimum value α of this complementary color data and an identification code S for indicating, among the six hue data, data which are zero.

The hue data calculator **102** receives the complementary color data Ci, Mi and Yi and the maximum and minimum values β and α, and outputs six hue data r, g, b, y, m and c which are obtained by executing the following subtraction:

r=β−Ci,

g=β−Mi,

b=β−Yi,

$y=Yi-\alpha$,
$m=Mi-\alpha$, and
$c=Ci-\alpha$.

Here, among the six hue data, at least two assume the value zero.

The polynomial calculator **103** receives the hue data and the identification code S, selects, from r, g and b, two data Q**1** and Q**2** which are not zero and, from y, m and c, two data P**1** and P**2** which are not zero. Based on these data, the polynomial calculator **103** computes polynomial data:

T**1**=P**1***P**2**,
T**3**=Q**1***Q**2**,
T**2**=T**1**/(P**1**+P**2**), and
T**4**=T**3**/(Q**1**+Q**2**),

and then outputs the results of the calculation.

It is noted that asterisks "*" are sometimes used in this specification to indicate multiplication.

The coefficient generator **105** generates calculation coefficients U(Fij) and fixed coefficients U(Eij) for the polynomial data based on information of the identification code S. The matrix calculator **104** receives the hue data y, m and c, the polynomial data T**1** to T**4** and the coefficients U, and outputs the result of the following formula (13) as color ink data C**1**, M**1** and Y**1**.

$$\begin{bmatrix} C1 \\ M1 \\ Y1 \end{bmatrix} = (Eij)\begin{bmatrix} c \\ m \\ y \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ c*m/(c+m) \\ m*y/(m+y) \\ y*c/(y+c) \\ r*g/(r+g) \\ g*b/(g+b) \\ b*r/(b+r) \end{bmatrix} \quad (13)$$

The synthesizer **106** adds together the color ink data C**1**, M**1** and Y**1** and data α which is the achromatic data, and outputs printing data C, M and Y. Accordingly, the following formula (14) is used for obtaining printing data.

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = (Eij)\begin{bmatrix} c \\ m \\ y \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ c*m/(c+m) \\ m*y/(m+y) \\ y*c/(y+c) \\ r*g/(r+g) \\ g*b/(g+b) \\ b*r/(b+r) \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \quad (14)$$

The formula (14) shows a general formula for a group of pixels.

FIG. **21**A to FIG. **21**F, which are schematic diagrams, show relations between six hues of red (R), green (G), blue (B), yellow (Y), cyan (C) and magenta (M), and hue data y, m, c, r, g and b. As shown, each hue data relates to three hues (i.e., extends over the range of three hues). For instance the hue data c relates to the hues g, c and b.

FIG. **22**A to FIG. **22**F, which are schematic diagrams, show relations between the six hues and product terms y*m, r*g, c*y, g*b, m*c and b*r.

As shown, each of the six product terms y*m, m*c, c*y, r*g, g*b and b*r in the formula (14) relates to only one hue among the six hues of red, blue, green, yellow, cyan and magenta. That is, only y*m is an effective product term for red; m*c for blue; c*y for green; r*g for yellow; g*b for cyan; and b*r for magenta.

Also, each of the six fraction terms y*m/(y+m), m*c/(m+c), c*y/(c+y), r*g/(r+g), g*b/(g+b) and b*r/(b+r) in the formula (14) relates to only one hue among the six hues.

As apparent from the foregoing, according to the color conversion method shown in FIG. **20**, by changing coefficients for the product terms and the fraction terms regarding the specific hue, only the target hue can be adjusted without influencing other hues.

Each of the foregoing product terms is determined by a second-order computation for chroma, and each of the fraction terms is determined by a first-order computation for chroma. Thus, by using both of the product terms and the fraction terms, the non-linearity of an image-printing for chroma can be adjusted.

However, this color conversion method cannot satisfy a certain desire. That is, depending on the user's preference, if an area in a color space occupied by specific hues is to be expanded or reduced, e.g., specifically, if expansion or reduction in an area of red in a color space including magenta red and yellow is desired, the conventional color conversion method of the matrix computation type could not meet such a desire.

The problems of the conventional color conversion method or color conversion device are summarized as follows. Where the color conversion device is of a three-dimensional look-up table conversion method employing a memory such as ROM, a large-capacity memory is required, and a conversion characteristic cannot be flexibly changed. Where the color conversion device is of a type using a matrix calculation method, although it is possible to change only a target hue, it is not possible to vary the color in the inter-hue areas between adjacent ones of the six hues of red, blue, green, yellow, cyan and magenta, and good conversion characteristics cannot be realized throughout the entire color space. Moreover, with the matrix conversion method shown in FIG. **20**, when the output of the output device represented by the reflectivity or luminance, or the like has a non-linear gray scale characteristics with respect to the image data, as in the case of a printing device, a cathode-ray tube display device, liquid crystal display device, or the like, desirable conversion characteristics cannot be obtained.

SUMMARY OF THE INVENTION

The present invention was made to solve the foregoing problems.

An object of the present invention is to provide a color conversion device and a color conversion method for performing color-conversion wherein independent adjustment is performed not only for six hues of red, blue, green, yellow, cyan and magenta but also six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta and magenta-red, and a conversion characteristic can be flexibly changed, and a good conversion can be achieved even when an output device has a non-linear characteristics, and no large-capacity memories, such as three-dimensional look-up tables, are necessary.

According to a first aspect of the invention, there is provided a color conversion device for performing pixel-by-pixel color conversion from a first set of three color data representing red, green and blue, or cyan, magenta and yellow, into a second set of three color data representing red, green and blue, or cyan, magenta, and yellow, said device comprising:

first calculation means for calculating a minimum value α and a maximum value β of said first set of three color data for each pixel;

hue data calculating means for calculating hue data r, g, b, y, m and c based on said first set of three color data, and said minimum and maximum values α and β outputted from said calculating means;

means for generating first comparison-result data based on the hue data outputted from said hue data calculating means;

means for generating second comparison-result data based on said first comparison-result data;

second calculation means for performing calculation using the hue data outputted from said hue data calculating means to produce calculation result data;

coefficient generating means for generating specified matrix coefficients for the hue data, the calculation result data, the first comparison-result data and the second comparison-result data;

third calculation means responsive to said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients from said coefficient generating means for calculating a third set of three color data representing red, green and blue, or cyan, magenta, and yellow, said third calculation means performing calculation including matrix calculation performed at least on said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients from said coefficient generating means; and

gray scale conversion means for converting the gray scale of said third set of three color data, to produce said second set of three color data.

Since the second set of three color data is obtained by gray scale conversion of the third set of three color data, the second set are of the same combination of colors as the third set. That is, if the third set comprises red, green and blue, the second set also comprises red, green and blue. If the third set comprises cyan, magenta and yellow, the second set also comprises cyan, magenta and yellow.

With the above arrangement, it is possible to independently vary not only the colors of the six hues of red, blue, green, yellow, cyan and magenta, but also the colors in the six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red. Moreover, by performing the gray scale conversion by means of the gray scale conversion means, it is possible to compensate for third-order or higher-order non-linearities, or complicated, non-linear characteristics (e.g., S-shaped characteristics) such as the one which liquid-crystal displays exhibit, and which cannot be obtained just by combining the first-order and second-order calculations. Accordingly, it is possible to obtain color conversion methods or color conversion devices which can change the conversion characteristics flexibly, without requiring a large-capacity memory. It is noted that the gray scale conversion means can be realized by a one-dimensional look-up table, and its size is much smaller than the three-dimensional look-up table.

Moreover, because the second comparison-result data calculated from the first comparison-result data are used as calculation term relating to the inter-hue areas in the matrix calculation, the number of calculation steps required can be reduced than if they are calculated from the hue data r, g, b, y, m, c.

It may be so configured that

said third calculation means performs said matrix calculation on said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients from said coefficient generating means, and further includes synthesizing means for adding said minimum value α from said first calculation means to the results of said matrix calculation.

It may be so configured that

said coefficient generating means generates predetermined matrix coefficients Eij (i=1 to 3, j=1 to 3), and Fij (i=1 to 3, j=1 to 18), and

said third calculation means performs the calculation using the hue data, said first comparison-result data, said second comparison-result data, said calculation result data, said minimum value α from said calculating means, and said matrix coefficients to determine the third set of three color data representing red, green and blue, denoted by Ro, Go and Bo, in accordance with the following formula (1):

$$\begin{bmatrix} Ro \\ Go \\ Bo \end{bmatrix} = (Eij)\begin{bmatrix} r \\ g \\ b \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \tag{1}$$

wherein h1r, h1g, h1b, h1c, h1m and h1y denote said first comparison-result data, and h2ry, h2rm, h2gy, h2gc, h2bm and h2bc denote said second comparison result data.

It may be so configured that

said coefficient generating means generates predetermined matrix coefficients Eij (i=1to 3, j=1 to 3), and Fij (i=1 to 3, j=1 to 18), and

said third calculation means performs the calculation using the hue data, said first comparison-result data, said second comparison-result data, said calculation result data, said minimum value α from said calculating means, and said matrix coefficients to determine the third set of three color data representing cyan, magenta and yellow denoted by Co, Mo and Yo, in accordance with the following formula (2):

$$\begin{bmatrix} Co \\ Mo \\ Yo \end{bmatrix} = (Eij)\begin{bmatrix} c \\ m \\ y \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \qquad (2)$$

wherein h**1**r, h**1**g, h**1**b, h**1**c, h**1**m and h**1**y denote said first comparison-result data, and h**2**ry, h**2**rm, h**2**gy, h**2**gc, h**2**bm and h**2**bc denote said second comparison result data.

It may be so configured that said third calculation means performs said matrix calculation on said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, the coefficients from said coefficient generating means, and said minimum value α from said first calculation means.

It may be so configured that

said coefficient generating means generates predetermined matrix coefficients Eij (i=1 to 3, j=1 to 3), and Fij (i=1 to 3, j=1 to 19), and

said third calculation means performs the calculation using the hue data, said first comparison-result data, said second comparison-result data, said calculation result data, said minimum value α from said calculating means, and said matrix coefficients to determine the third set of three color data representing red, green and blue, denoted by Ro, Go and Bo, in accordance with the following formula (3):

$$\begin{bmatrix} Ro \\ Go \\ Bo \end{bmatrix} = (Eij)\begin{bmatrix} r \\ g \\ b \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \\ \alpha \end{bmatrix} \qquad (3)$$

wherein h**1**r, h**1**g, h**1**b, h**1**c, h**1**m and h**1**y denote said first comparison-result data, and h**2**ry, h**2**rm, h**2**gy, h**2**gc, h**2**bm and h**2**bc denote said second comparison result data.

It may be so configured that

said coefficient generating means generates predetermined matrix coefficients Eij (i=1 to 3, j=1 to 3), and Fij (i=1 to 3_1, j=1 to 19), and

said third calculation means performs the calculation using the hue data, said first comparison-result data, said second comparison-result data, said calculation result data, said minimum value α from said calculating means, and said matrix coefficients to determine the third set of three color data representing cyan, magenta and yellow denoted by Co, Mo and Yo, in accordance with the following formula (4):

$$\begin{bmatrix} Co \\ Mo \\ Yo \end{bmatrix} = (Eij)\begin{bmatrix} c \\ m \\ y \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \\ \alpha \end{bmatrix} \qquad (4)$$

wherein h**1**r, h**1**g, h**1**b, h**1**c, h**1**m and h**1**y denote said first comparison-result data, and h**2**ry, h**2**rm, h**2**gy, h**2**gc, h**2**bm and h**2**bc denote said second comparison result data.

It may be so configured that

said first set of three color data represent red, green and blue,

said third set of three color data represent red, green and blue, and

said hue data calculation means calculates the hue data r, g, b, y, m, c by subtraction in accordance with:

r=Ri−α,

g=Gi−α,

b=Bi−α,

y=β−Bi,

m=β−Gi, and

c=β−Ri,

wherein Ri, Gi and Bi represent said first set of three color data.

It may be so configured that

said first set of three color data represent cyan, magenta and yellow,

said third set of three color data represent red, green and blue,

said device further comprises means for determining complement of said first set of three color data, and

said hue data calculation means calculates the hue data r, g, b, y, m, c by subtraction in accordance with:

r=Ri−α,

g=Gi−α,

b=Bi−α,

$y=\beta-Bi$,
$m=\beta-Gi$, and
$c=\beta-Ri$,

wherein Ri, Gi and Bi represent data produced by the determination of the complement of said first set of three color data.

It may be so configured that

said first set of three color data represent cyan, magenta and yellow,

said third set of three color data represent cyan, magenta and yellow, and

said hue data calculation means calculates the hue data r, g, b, y, m, c by subtraction in accordance with:

$r=\beta-Ci$,
$g=\beta-Mi$,
$b=\beta-Yi$,
$y=Yi-\alpha$,
$m=Mi-\alpha$, and
$c=Ci-\alpha$,

wherein Ci, Mi and Yi represent said first set of three color data.

It may be so configured that

said first set of three color data represent red, green and blue,

said third set of three color data represent cyan, magenta and yellow,

said device further comprises means for determining complement of said first set of three color data, and

said hue data calculation means calculates the hue data r, g, b, y, m, c by subtraction in accordance with:

$r=\beta-Ci$,
$g=\beta-Mi$,
$b=\beta-Yi$,
$y=Yi-\alpha$,
$m=Mi-\alpha$, and
$c=Ci-\alpha$

wherein Ci, Mi and Yi represent data produced by the determination of the complement of said first set of three color data.

With the above arrangement, the hue data calculating means can be configured of means for performing subtraction based on the input image of red, green and blue, or cyan, magenta and yellow and the maximum value β and minimum value α from the first calculation means.

It may be so configured that

said first comparison-result data generating means determines the comparison-result data among the hue data r, g and b, and the comparison-result data among the hue data y, m and c, and

said second comparison-result data generating means comprises multiplying means for multiplying the first comparison-result data outputted from said first comparison-result data generating means with specific calculation coefficients, and means for determining the comparison-result data based on the outputs of said multiplication means.

With the above arrangement, the first comparison-result data generating means and the second comparison-result data generating means are configured of means for performing comparison, and means for performing multiplication.

It may be so configured that

said first comparison-result data generating means determines the first comparison-result data:

h1r=min (m, y),
h1g=min (y, c),
h1b=min (c, m),
h1c=min (g, b),
h1m=min (b, r), and
h1y=min (r, g),

(with min (A, B) representing the minimum value of A and B),

said second comparison-result data generating means determines the second comparison-result data:

h2ry=min (aq1*h1y, ap1*h1r),
h2rm=min (aq2*h1m, ap2*h1r),
h2gy=min (aq3*h1y, ap3*h1g),
h2gc=min (aq4*h1c, ap4*h1g),
h2bm=min (aq5*h1m, ap5*h1b), and
h2bc=min (aq6*h1c, ap6*h1m).

With the above arrangement, the first comparison-result data generating means can be configured of means for performing minimum value selection, and the second comparison-result data can be configured of means for performing multiplication and means for performing minimum value selection.

It may be so configured that said multiplying means in said second comparison-result data generating means performs calculation on said first comparison result-data and said calculation coefficients by setting said calculation coefficients aq1 to aq6 and ap1 to ap6 to integral values of 2^n, with n being an integer, and by bit shifting.

With the above arrangement, the multiplication can be carried out by means of bit shifting.

It may be so configured that said second calculation means determines products of the hue data.

With the above arrangement, said second calculation means can be configured of means for performing multiplication.

It may be so configured that each of said first comparison-result data is determined from two of the hue data and is effective for only one of the six hues of red, green, blue, cyan, magenta and yellow.

With the above arrangement, each of the six hues can be adjusted by varying the coefficients for the first comparison-result data without influencing other hues.

It may be so configured that

each of said second comparison-result data is determined from two of the first comparison-result data and is effective for only one of the six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red.

With the above arrangement, each of the six inter-hue areas can be adjusted by varying the coefficients for the second comparison-result data without influencing other inter-hue areas.

It may be so configured that

said coefficient generating means generates specified matrix coefficients Eij (i=1 to 3, j=1 to 3) based on a formula (5) below:

$$(Eij)=\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} \tag{5}$$

and generates the matrix coefficients Fij (i=1 to 3, j=1 to 18, or j=1 to 19) such that, of the coefficients Fij, the coefficients for said calculation result data are set to zero, and other coefficients are set to specified values.

With the above arrangement, it is not necessary to calculate the product terms for which the coefficients are zero, and yet it is possible to linearly adjust only the target hue or inter-hue area (among the six hues of red, blue, green, yellow, cyan and magenta, and the six inter-hue areas) without influencing other hues or inter-hue areas.

It may be so configured that

said first calculation means calculates a maximum value β and a minimum value α using said first set of three color data, and generates an identification code indicating the hue data which is of a value zero, and

said second calculation means performs arithmetic operation on said hue data based on the identification code outputted from said first calculation means,

said coefficient generating means generates said matrix coefficients based on the identification code outputted from said first calculation means, and

said third calculation means performs matrix calculation using the coefficient from said coefficient generating means to produce the third set of three color data based on the identification code outputted from said first calculation means.

With the above arrangement, the number of steps for performing the matrix calculation can be reduced.

According to another aspect of the invention, there is provided a color conversion method of performing pixel-by-pixel color conversion from a first set of three color data representing red, green and blue, or cyan, magenta and yellow, into a second set of three color data representing red, green and blue, or cyan, magenta, and yellow, said method comprising the steps of:

(a) calculating a minimum value α and a maximum value β of said first set of three color data for each pixel;

(b) calculating hue data r, g, b, y, m and c based on said first set of three color data, and said minimum and maximum values α and β obtained at said step (a);

(c) generating first comparison-result data based on the hue data obtained at said step (b);

(d) generating second comparison-result data based on said first comparison-result data;

(e) performing calculation using the hue data obtained at said step (b) to produce calculation result data;

(f) generating specified matrix coefficients for the hue data, the calculation result data, the first comparison-result data and the second comparison-result data; and

(g) calculating, responsive to said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients generated at said step (f), a third set of three color data representing red, green and blue, or cyan, magenta and yellow; and

(h) converting the gray scale of said third set of three color data, to produce said second set of three colors;

said step (g) comprising the step of performing matrix calculation on at least said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients obtained at said step (f).

Said step (g) may comprise the steps of:

(g**1**) performing said matrix calculation on said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, and the coefficients obtained at said step (f), and

(g**2**) adding said minimum value α calculated at said step (a).

Said step (g) may alternatively comprise the step of performing said matrix calculation on said hue data, said first comparison-result data, said second comparison-result data, said calculation result data, the coefficients obtained at said step (f), and said minimum value α obtained at said step (a).

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1** is a block diagram showing an example of configuration of a color conversion device of Embodiment 1 of the present invention;

FIG. **2** is a block diagram showing an example of configuration of a polynomial calculator included in the color conversion device of Embodiment 1;

FIG. **3** is a table showing an example of the relationship between an identification code S**1**, and the maximum and minimum values β and α, and hue data whose value is zero, in the color conversion device of Embodiment 1;

FIG. **4** is a table showing the operation of a zero remover of the polynomial calculator in the color conversion device of Embodiment 1;

FIG. **5** is a block diagram showing an example of configuration of a matrix calculator included in the color conversion device of Embodiment 1;

FIG. **6**A to FIG. **6**F are diagrams schematically showing the relationship between six six hues and hue data;

FIG. **7**A to FIG. **7**F are diagrams schematically showing the relationship between six hues and product terms in the color conversion device of Embodiment 1;

FIG. **8**A to FIG. **8**F are diagrams schematically showing the relationship between six hues and first comparison-result data in the color conversion device of Embodiment 1;

FIG. **9**A to FIG. **9**F are diagrams schematically showing the relationship between six inter-hue areas and second comparison-result data in the color conversion device of Embodiment 1;

FIG. **10**A to FIG. **10**F are diagrams schematically showing how the range of each inter-hue area is changed with the change of the coefficients multiplied at the polynomial calculator is changed;

FIG. **11**A and FIG. **11**B are tables showing the relationship between respective hues or inter-hue areas, and effective calculation terms or data which relate to and are effective for each hue or inter-hue area;

FIG. **12** is an xy chromaticity diagram illustrating the gamut of the color reproduction of the input color signals and the gamut of a desired color reproduction, for explaining the operation of Embodiment 1;

FIG. **13** is an xy chromaticity diagram illustrating the gamut of the color reproduction obtained by adjusting the coefficients for the first comparison-result data, together with the gamut of the desired color reproduction, for explaining the operation of Embodiment 1;

FIG. **14** is an xy chromaticity diagram for explaining the gamut of the color reproduction obtained by adjusting the coefficients for the first and second comparison-result data, together with the gamut of the desired color reproduction, for explaining the operation of Embodiment 1;

FIG. **15** is a block diagram showing an example of configuration of a color conversion device of Embodiment 2 of the present invention;

FIG. **16** is a block diagram showing an example of configuration of Embodiment 3 of the present invention;

FIG. **17** is a block diagram showing part of an example of configuration of a matrix calculator included in the color conversion device of Embodiment 3;

FIG. **18** is a block diagram showing an example of configuration of a color conversion device of Embodiment 4 of the present invention;

FIG. **19** is a block diagram showing an example of configuration of a color conversion device of Embodiment 5 of the present invention;

FIG. **20** is a block diagram showing an example of configuration of a conventional color conversion device;

FIG. **21**A to FIG. **21**F are diagrams schematically showing the relationship between six hues and hue data in the conventional color conversion device; and

FIG. **22**A to FIG. **22**F are diagrams schematically showing the relationship between six hues and calculation terms in a matrix calculator included in the conventional color conversion device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Next, the preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings.

Embodiment 1

FIG. **1** is a block diagram showing an example of configuration of a color conversion device of Embodiment 1 of the present invention. The illustrated color conversion device is for converting a first set of three color data representing red, green and blue, denoted by Ri, Gi and Bi, into a second set of three color data, also representing red, green and blue, denoted by Rp, Gp and Bp. A minimum and maximum calculator **1** calculates a maximum value β and a minimum value α of the inputted first set of three colors, also called image data Ri, Gi and Bi, and generates and outputs an identification code S**1** for indicating, among the six hue data, data which are zero, as will be better understood from the following description. A hue data calculator **2** calculates hue data r, g, b, y, m and c from the image data Ri, Gi and Bi and the outputs from the minimum and maximum calculator **1**. The color conversion device further comprises a polynomial calculator **3**, a matrix calculator **4**, a coefficient generator **5**, and a synthesizer **6**. The synthesizer **6** outputs a third set of three color data, denoted by Ro, Go and Bo.

A gray scale converters **15***a*, **15***b* and **15***c* respectively convert the gray scale, i.e., tone of the third set of three color data, Ro, Go and Bo, and output the second set of image data Rp, Gp and Bp.

FIG. **2** is a block diagram showing an example of configuration of the polynomial calculator **3**. In FIG. **2**, a zero remover **7** removes, from the inputted hue data, data which are of value zero. Reference numerals **8***a* and **8***b* denote multipliers. Minimum selectors **9***a*, **9***b* and **9***c* select and output the minimum of the input data. A calculation coefficient generator **11** generates and outputs calculation coefficients based on the identification code S1 from the minimum and maximum calculator **1**. Arithmetic units **10***a* and **10***b* perform multiplication between the calculation coefficients represented by the outputs of the calculation coefficient generator **11** and the outputs from the minimum selectors **9***a* and **9***b*.

Next, the operation will be described. The inputted image data Ri, Gi and Bi corresponding to the three colors of red, green and blue are sent to the minimum and maximum calculator **1** and the hue data calculator **2**. The minimum and maximum calculator **1** calculates and outputs a maximum value β and a minimum value α of the inputted image data Ri, Gi and Bi, and also generates and outputs an identification code S**1** for indicating, among the six hue data, data which are zero.

The hue data calculator **2** receives the inputted image data Ri, Gi and Bi and the maximum and minimum values β and α from the minimum and maximum calculator **1**, performs subtraction of

r=Ri−α,
g=Gi−α,
b=Bi−α,
y=β−Bi,
m=β−Gi, and
c=β−Ri,

and outputs six hue data r, g, b, y, m and c thus obtained.

The maximum and minimum values β and α calculated by the minimum and maximum calculator **1** are respectively represented as follows:

β=MAX (Ri, Gi, Bi)
α=MIN (Ri, Gi, Bi)

Since the six hue data r, g, b, y, m and c calculated by the hue data calculator **2** are obtained by the subtraction of

r=Ri−α,
g=Gi−α,
b=Bi−α,
y=β−Bi,
m=β−Gi, and
c=β−Ri,

at least two among these six hue data are of a value zero. For example, if a maximum value β is Ri and a minimum value α is Gi (β=Ri, and α=Gi), g=0 and c=0. If a maximum value β is Ri and a minimum value α is Bi (β=Ri, and α=Bi), b=0 and c=0. In other words, in accordance with a combination of Ri, Gi and Bi which are the largest and the smallest, respectively, one of r, g and b, and one of y, m and c, i. e., in total two of them have a value zero.

Thus, in the foregoing minimum and maximum calculator **1**, the identification code S**1** for indicating, among the six hue data which are zero are generated and outputted. The identification code S**1** can assume one of the six values, depending on which of Ri, Gi and Bi are of the maximum and minimum values β and α. FIG. **3** shows a relationship between the values of the identification code S**1** and the maximum and minimum values β and α of Ri, Gi and Bi and hue data which has a value zero. In the drawing, the values of the identification code S**1** represent just an example, and the values may be other than those shown in the drawing.

Then, the six hue data r, g, b, y, m and c outputted from the hue data calculator **2** are sent to the polynomial calculator **3**, and the hue data r, g and b are also sent to the matrix calculator **4**. The polynomial calculator **3** also receives the identification code S**1** outputted from the minimum and maximum calculator **1**, and performs calculation by selecting, from the hue data r, g and b, two data Q**1** and Q**2** which are not of a value zero, and from the hue data y, m and c, two data P**1** and P**2** which are not of a value zero. Next, this operation will be described by referring to FIG. **2**.

The hue data from the hue data calculator **2** and the identification code S**1** from the minimum and maximum calculator **1** are inputted to the zero remover **7** in the polynomial calculator **3**. The zero remover **7** outputs, based on the identification code S**1**, the two data Q**1** and Q**2** which are not of a value zero, among the hue data r, g and b and the two data P**1** and P**2** which are not of a value zero, among the hue data y, m and c. For instance, Q**1**, Q**2**, P**1** and P**2** are determined as shown in FIG. **4**, and then outputted. If, for example, the identification code Si is of a value zero, Q1 and Q2 are obtained from the hue data r and b, and P1 and P2 are obtained from the hue data y and m, so the outputs are given by Q1=r, Q2=b, P1=m and P2=y. As in the case of FIG. **3**, the values of the identification code S1 in FIG. **4** represent just an example, and may be other than those shown in FIG. **4**.

The data Q1 and Q2 outputted from the zero remover **7** are inputted to the multiplier **8***a*, which calculates and outputs the product T3=Q1*Q2. The data P1 and P2 outputted from the zero remover **7** are inputted to the multiplier **8***b*, which calculates and outputs the product T1=P1*P2.

The minimum selector **9***a* selects and outputs the minimum value T4=min (Q1, Q2) among the output data Q1 and Q2 from the zero remover **7**. The minimum selector **9***b* selects and outputs the minimum value T2=min (P1, P2) among the output data P1 and P2 from the zero remover **7**. The outputs of the minimum selectors **9***a* and **9***b* are the first comparison-result data.

The identification code S1 is inputted from the minimum and maximum calculator **1** to the calculation coefficient generator **11**, which generates signals indicating calculation coefficients aq and ap based on the identification code S1, and the coefficient aq is supplied to the arithmetic unit **10***a*, and the coefficient ap is supplied to the arithmetic unit **10***b*. These calculation coefficients aq and ap are used for multiplication with the comparison-result data T4 and T2, and each of the calculation coefficients aq and ap can assume one of the six values, corresponding to the value of the identification code S1 shown in FIG. **4**. The arithmetic unit **10***a* receives the comparison-result data T4 from the minimum selector **9***a*, performs multiplication of aq*T4, and sends the result to the minimum selector **9***c*. The arithmetic unit **10***b* receives the comparison-result data T2 from the minimum selector **7**, performs multiplication of ap*T2, and sends the result to the minimum selector **9***c*.

The minimum selector **9***c* selects and outputs the minimum value T5=min (aq*T2, ap*T4) of the outputs the arithmetic units **10***a* and **10***b*. The output of the minimum value selector **9***c* is a second comparison-result data.

The polynomial data T1, T2, T3, T4 and T5 outputted from the polynomial calculator **3** are supplied to the matrix calculator **4**.

The coefficient generator **5** shown in FIG. **1** generates calculation coefficients U (Fij) and fixed coefficients U (Eij) for the polynomial data based on the identification code S1, and sends the same to the matrix calculator **4**.

The matrix calculator **4** receives the hue data r, g and b from the hue data calculator **2**, the polynomial data T1 to T5 from the polynomial calculator **3** and the coefficients U from the coefficient generator **5**, and outputs the results of calculation according to the following formula (6) as image data R1, G1 and B1.

$$\begin{bmatrix} R1 \\ G1 \\ B1 \end{bmatrix} = (Eij)\begin{bmatrix} r \\ g \\ b \end{bmatrix} + (Fij)\begin{bmatrix} T1 \\ T2 \\ T3 \\ T4 \\ T5 \end{bmatrix} \tag{6}$$

For (Eij), i=1 to 3 and j=1 to 3, and for (Fij), i=1 to 3 and j=1 to 5.

FIG. **5**, which is a block diagram, shows an example of configuration of part of the matrix calculator **4**. Specifically, it shows how R1 is calculated and outputted. As shown in FIG. **5**, the matrix calculator **4** includes multipliers **12***a* to **12***f*, and adders **13***a* to **13***e* interconnected as illustrated.

Next, the operation of the matrix calculator **4** of FIG. **5** will be described. The multipliers **12***a* to **12***f* receive the hue data r, the polynomial data T1 to T5 from the polynomial calculator **3** and the coefficients U (Eij) and U (Fij) from the coefficient generator **5**, and then output the products thereof. The adders **13***a* and **13***b* receive the products outputted from the multipliers **12***b* to **12***e*, add the inputted data and output the sums thereof. The adder **13***c* adds the data from the adders **13***a* and **13***b*, and the adder **13***d* adds the output from the adder **13***c* and the product outputted from the multiplier **12***f*. The adder **13***e* adds the output from the adder **13***d* and the output from the multiplier **12***a*, and outputs the sum total thereof as image data R1. In the example of configuration shown in FIG. **5**, if the hue data r is replaced by the hue data g or b, and coefficients suitable for the respective terms (data) T1 to T5 are used in substitution, image data G1 or B1 can be calculated.

Where it is desired to increase the calculation speed of the color conversion method or the color conversion device of this embodiment, since parts of the coefficients (Eij) and (Fij) which respectively correspond to the hue data r, g and b are used, the configurations each as shown in FIG. **5** may be used in parallel, so as to perform the matrix calculation at a higher speed.

The synthesizer **6** receives the image data R1, G1 and B1 from the matrix calculator **4** and the minimum value α outputted from the minimum and maximum calculator **1** representing the achromatic data, performs addition, and outputs image data Ro, Go and Bo. The equation used for obtaining the image data color-converted by the color-conversion method of FIG. **1** is therefore given by the following formula (1).

$$\begin{bmatrix} Ro \\ Go \\ Bo \end{bmatrix} = (Eij)\begin{bmatrix} r \\ g \\ b \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \tag{1}$$

Here, for (Eij), i=1 to 3 and j=1 to 3, and for (Fij), i=1 to 3 and j=1 to 18, and

h1r=min (m, y),

h1g=min (y, c),

h1b=min (c, m),

h1c=min (g, b),

h1m=min (b, r),

h1y=min (r, g),

h2ry=min (aq1*h1y, ap1*h1r),
h2rm=min (aq2*h1m, ap2*h1r),
h2gy=min (aq3*h1y, ap3*h1g),
h2gc=min (aq4*h1c, ap4*h1g),
h2bm=min (aq5*h1m, ap5*h1b), and
h2bc=min (aq6*h1c, ap6*h1b),

and aq1 to aq6 and ap1 to ap6 indicate calculation coefficients generated by the calculation coefficient generator 11 of FIG. 2.

The difference between the number of calculation terms in the formula (1) and the number of calculation terms in FIG. 1 is that FIG. 1 shows a method of calculation for each pixel excluding the calculation terms which are of a value zero, while the formula (1) represents a general formula for a set of pixels. In other words, eighteen polynomial data for one pixel of the formula (1) can be reduced to five effective data, and this reduction is achieved by exploiting a characteristic of the hue data.

The combination of effective data is changed according to image data of the target pixel. For all image data, all the polynomial data can be effective.

FIG. 6A to FIG. 6F schematically show relations between the six hues (red, yellow, green, cyan, blue, magenta) and the hue data y, m, c, r, g and b. Each hue data relates to, i.e., extends to cover the range of three hues. For example, y as shown in FIG. 6A relates to, or extends to cover three hues of red, yellow and green.

FIG. 7A to FIG. 7F schematically show relations between the six hues and the product terms y*m, r*g, c*y, g*b, m*c and b*r, and it can be understood that each product term is a second-order term for a specified hue. For example, if W is a constant, since r=W and g=b=0 hold for red, y=m=W and c=0 are obtained. Accordingly, y*m=W*W is realized, and this term is a second-order term. The other five terms are all zero. In other words, only y*m is an effective second-order term for red. Similarly, c*y is the only effective term for green; m*c for blue; g*b for cyan; b*r for magenta; and r*g for yellow.

Each of the foregoing formulae (6) and (1) includes a first comparison-result data effective only for one hue. The first comparison-result data are:

h1r=min (y, m),
h1y=min (r, g)
h1g=min (c, y),
h1c=min (g, b),
h1b=min (m, c), and
h1m=min (b, r).

FIG. 8A to FIG. 8F schematically show relations between the six hues and first comparison-result data h1r, h1y,h1g, h1c, h1b, and h1m. It is seen that each of the first comparison-result data relates to only one specific hue.

The six first comparison-result data has the nature of a first-order term. For instance, if W is a constant, for red, r=W, g=b=0, so that y=m=W, and c=0. As a result, min (y, m)=W has a first-order value. The other five first comparison-result data are all of a value zero. That is, for red, h1r=min (y, m) alone is the only effective first comparison-result data. Similarly, h1g=min (c, y) is the only effective first comparison-result data for green; h1b=min (m, c) for blue; h1c=min (g, b) for cyan; h1m=min (b, r) for magenta; and h1y=min (r, g) for yellow.

Next, a difference between the first-order and second-order terms will be described. As described above, for red, if W is a constant, y*m=W*W is realized, and the other product terms are all zero. Here, since the constant W indicates the magnitudes of the hue signals y and m, the magnitude of the constant W depends on the color brightness or chroma. With y*m=W*W, the product term y*m is a second-order function for chroma. The other product terms are also second-order functions for chroma regarding the hues to which these terms are effective. Accordingly, influence given by each product term to color reproduction is increased in a second-order manner as chroma is increased. In other words, the product term is a second-order term which serves as a second-order adjustment term for chroma in color reproduction.

On the other hand, for red, if W is a constant, h1r=min (m, m)=W is realized, and the other first comparison-result data are all zero. Here, the magnitude of the constant W depends of color brightness or chroma. With h1r=min (y, m)=W, the comparison-result data h1r=min (y, m) is a first-order function for chroma. The other first comparison-result data are also first-order functions for chroma regarding the hues to which these terms are effective. Accordingly, the influence given by each first comparison-result data to color reproduction is a first-order function for chroma. In other words, the first comparison-result data is a first-order term which serves as a first-order adjustment term for chroma in color reproduction.

FIG. 9A to FIG. 9F schematically show relations between the six hues and second comparison-result data:

h2ry=min (h1y, h1r),
h2gy=min (h1y, h1g),
h2gc=min (h1c, h1g),
h2bc=min (h1c, h1b),
h2bm=min (h1m, h1b), and
h2rm=min (h1m, h1r).

This is the case in which the coefficients aq1 to aq6 and ap1 to ap6 in

h2ry=min (aq1*h1y, ap1*h1r),
h2rm=min (aq2*h1m, ap2*h1r),
h2gy=min (aq3*h1y, ap3*h1g),
h2gc=min (aq4*h1c, ap4*h1g),
h2bm=min (aq5*h1m, ap5*h1b), and
h2bc=min (aq6*h1c, ap6*h1b),

in the formula (1) above are all of a value “1”.

It can be understood from FIG. 9A to FIG. 9F, that each of the second comparison-result data relates to changes in the six inter-hue areas of red-green, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red. In other words, for red-yellow, b=c=0, and the five terms other than h2ry=min (h1y, h1r)=min (min (r, g) min (y, m)) are all zero. Accordingly, only h2ry is an effective second comparison-result data for red-yellow. Similarly, only h2gy is an effective second comparison-result data for yellow-green; h2gc for green-cyan; h2bc for cyan-blue; h2bm for blue-magenta; and h2rm for magenta-red.

Moreover, the range of the inter-hue area to which each of the second comparison-result data relates is half that of the range of the hue to which each of the first comparison-result data relates.

FIG. 10A to FIG. 10F schematically show how the range of the six inter-hue area to which each of the second comparison-result data relate is changed when the coefficients aq1 to aq6 and ap1 to ap6 used for determination of h2ry, h2rm, h2gy, h2gc, h2bm and h2bc according to the foregoing formulae (6) and (1) are changed. The broken lines a1 to a6 shows the characteristics when aq1 to aq6 assume values larger than ap1 to ap6. The broken lines b1 to b6 shows the characteristics when ap1 to ap6 assume values larger than aq1 to aq6.

Specifically, for inter-hue area red-yellow, only h**2**ry=min (aq**1***h**1**y, ap**1***h**1**r) is an effective second comparison-result data. If, for example, the ratio between aq**1** and ap**1** is 2:1, the peak value of the second comparison-result data is shifted toward red, as indicated by the broken line a**1** in FIG. **10**A, and thus it can be made an effective comparison-result data for an area closer to red in the inter-hue area of red-yellow. On the other hand, for example if the ratio between aq**1** and ap**1** is 1:2, the relationship is like that indicated by the broken line b**1** in FIG. **10**A, the peak value of the second comparison-result data is shifted toward yellow, and thus it can be made an effective comparison-result data for an area closer to yellow in the inter-hue area of red-yellow. Similarly, by respectively changing:

aq**3** and ap**3** in h**2**gy for yellow green,
aq**4** and ap**4** in h**2**gc for green-cyan,
aq**6** and ap**6** in h**2**bc for cyan-blue,
aq**5** and ap**5** in h**2**bm for blue-magenta, and
aq**2** and ap**2** in h**2**rm for magenta-red,

in the area for which each second comparison-result data is most effective can be changed.

FIG. **11**A and FIG. **11**B respectively show relations between the six hues and inter-hue areas and effective calculation terms. Thus, if the coefficient generator **5** changes coefficients for a calculation term effective for a hue or an inter-hue area to be adjusted, only the target hue or inter-hue area can be adjusted. Further, if coefficients generated by the calculation coefficient generator **11** in the polynomial calculator **3** are changed, part of the inter-hue area where a calculation term in the inter-hue area is most effective can be changed without giving any influence to the other hues.

Next, an example of coefficients generated by the coefficient generator **5** of Embodiment 1 described above with reference to FIG. **1** will be described. The following formula (5) shows an example of coefficients U (Eij) generated by the coefficient generator **5**.

$$(Eij) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5}$$

If the coefficients U (Fij) in the foregoing formula are all zero this represents the case where color conversion is not executed. The following formula (7) shows the case where, of the coefficients U (Fij), the coefficients for second-order calculation terms which are product terms are all zero, and coefficients for first comparison-result data and second comparison-result data, both of which are first-order calculation terms, are represented by, for example Ar**1** to Ar**3**, Ay**1** to Ay**3**, Ag**1** to Ag**3**, Ac**1** to Ac**3**, Ab**1** to Ab**3**, Am**1** to Am**3**, Ary**1** to Ary**3**, Agy**1** to Agy**3**, Agc**1** to Agc**3**, Abc**1** to Abc**3**, Abm**1** to Abm**3** and Arm**1** to Arm**3**.

In the foregoing, adjustment is performed by using the first comparison-result data and second comparison-result data, both of which are first-order calculation terms. Accordingly, only a hue or an inter-hue area can be linearly adjusted. If coefficients relating to the first-order calculation term for a hue or an inter-hue area to be adjusted are set to values other than zero, and the other coefficients are made to be zero, only the target hue or inter-hue area can be adjusted. For example, if coefficients Ar**1** to Ar**3** relating to h**1**r relating to red are set, the red hue is changed, and to vary the colors in the red-to-yellow inter-hue area, the coefficients Ary**1** to Ary**3** relating to h**2**ry are used.

Where it is intended to make only linear adjustment of the hues and inter-hue areas, it is not necessary to calculate the product terms. In this case, the multipliers **8**a and **8**b in the polynomial calculator **3** shown in FIG. **2**, and the multipliers **12**b and **12**d, and the adders **13**a and **13**b in the matrix calculator **4** shown in FIG. **5** may be omitted. In this case, the non-linear characteristics taking into consideration the characteristics of the output device may be realized by the use of the gray scale converters **15**a, **15**b and **15**c.

Furthermore, if, in the polynomial calculator **3**, the values of calculation coefficients aq**1** to aq**6** and ap**1** to ap**6** in

h**2**ry=min (aq**1***h**1**y, ap**1***h**1**r),
h**2**rm=min (aq**2***h**1**m, ap**2***h**1**r),
h**2**gy=min (aq**3***h**1**y, ap**3***h**1**g),
h**2**gc=min (aq**4***h**1**c, ap**4***h**1**g),
h**2**bm=min (aq**5***h**1**m, ap**5***h**1**b), and
h**2**bc=min (aq**6***h**1**c, ap**6***h**1**b)

are changed so as to assume integral values of 1, 2, 4, 8, . . . , i.e., 2^n (where n is an integer), multiplication can be achieved in the arithmetic units **10**a and **10**b by bit shifting.

As apparent from the foregoing, by changing the coefficients for the product terms and first comparison-result data relating to specific hues, it is possible to adjust only the target hue among the six hues of red, blue, green, yellow, cyan and magenta, and by changing the coefficients for the second comparison-result data, it is possible to vary the colors in the six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red. The adjustment of each hue or inter-hue area can be achieved independently, i.e., without influencing other hues or other inter-hue areas.

Each of the foregoing product terms is a second-order calculation for chroma, and each of the first and second comparison-result data is a first-order calculation for chroma. Accordingly, by using the product terms, and the first and second comparison-result data, the non-linearity of an image printing or the like can be varied for chroma.

The image data Ro, Go and Bo outputted by the synthesizer **6** are inputted the gray scale converters **15**a, **15**b and **15**c, where gray scale correction is applied.

By performing the gray scale conversion at the gray scale converters **15**a, **15**b and **15**c, it is possible to compensate for third-order or higher-order non-linearities, or complicated, non-linear characteristics (e.g., S-shaped characteristics)

$$(Fij) = \tag{7}$$

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & Ar1 & Ag1 & Ab1 & Ac1 & Am1 & Ay1 & Ary1 & Arm1 & Agy1 & Agc1 & Abm1 & Abc1 \\ 0 & 0 & 0 & 0 & 0 & 0 & Ar2 & Ag2 & Ab2 & Ac2 & Am2 & Ay2 & Ary2 & Arm2 & Agy2 & Agc2 & Abm2 & Abc2 \\ 0 & 0 & 0 & 0 & 0 & 0 & Ar3 & Ag3 & Ab3 & Ac3 & Am3 & Ay3 & Ary3 & Arm3 & Agy3 & Agc3 & Abm3 & Abc3 \end{bmatrix}$$

such as the one which liquid-crystal displays exhibit, and which cannot be obtained just by combining the first-order and second-order calculations.

The gray scale converters **15***a*, **15***b* and **15***c* may be in the form of a one-dimensional look-up table, or a calculation means having the input-output characteristics of a power function.

Accordingly, it is possible to obtain color conversion methods or color conversion devices which can change the conversion characteristics flexibly, without requiring a large-capacity memory. It is noted that the gray scale converters can be realized by a one-dimensional look-up table, and its size is much smaller than the three-dimensional look-up table.

Further description on the operation of the color conversion device using the coefficients represented by the formulae (5) and (7) will be given. FIG. **12** to FIG. **14** show an xy chromaticity diagram showing the operation of the color conversion device of Embodiment 1. In FIG. **12** to FIG. **14**, the dotted line **21** represents the gamut of the desired color reproduction. In FIG. **12**, the triangle of the solid line **22** represents the gamut of color reproduction (reproducible colors) of the input color signals Ri, Gi and Bi. Here, the input color signals may be those for a certain type of image reproducing device, such as a display device, e.g., a CRT monitor. The "desired color reproduction" may be the color reproduction by another type of display device, or theoretical or imaginary color reproduction.

The directions of lines extending from the center of each triangle to the vertexes and points on the sides of the triangle represent respective hues.

In the example of FIG. **12**, there are differences between the color reproduction of the input color signals and the desired color reproduction with regard to the directions of the lines extending from the center of the triangle to the vertexes and points on the sides. This means that the hues of the reproduced colors are different.

The color conversion device of Embodiment 1 of the invention uses the first comparison-result data effective for each of the six hues, and the second comparison-result data effective for each of the inter-hue areas.

In FIG. **13**, the solid line **23** represents the gamut of the color reproduction after the adjustment of the coefficients for the first comparison-result data, while the broken line **24** represents the gamut of the color reproduction without the adjustment of the coefficients. As will be seen, the hues of the color reproduction as represented by the solid line **23** and the hues of the desired color reproduction as represented by the dotted line **21** coincide with each other. The coincidence is achieved by adjusting the coefficients for the first comparison-result data. However, it is noted that the gamut of the color reproduction as represented by the solid line **23** is narrower than the gamut of the color reproduction as represented by the broken line **24** (without the adjustment of the coefficients).

FIG. **14** shows the gamut **25** of the color reproduction obtained when both the coefficients for the first comparison-result data and the coefficients for the second comparison-result data are adjusted. By adjusting both the coefficients for the first and second comparison-result data, the hues of the color reproduction as represented by the line **25** coincides with the hues of the desired color reproduction, and the gamut **25** of the color reproduction obtained when both the coefficients for the first and second comparison-result data are identical to the gamut (**22** in FIG. **12**) of the color reproduction obtained when the coefficients for the first and second comparison-result data are not adjusted. That is, in the color conversion device according to Embodiment 1 of the invention, by adjusting the coefficients for the first and second comparison-result data, the hues can be adjusted without narrowing the gamut of the color reproduction.

In Embodiment 1 described above, the hue data r, g, b, y, m and c, and the maximum and minimum values β and α were calculated based on the inputted image data Ri, Gi and Bi so as to obtain the calculation terms for the respective hues, and the image data Ro, Go, Bo are obtained after the calculation according to the formula (1), and the image data Rp, Gp, Bp are obtained after the gray scale conversion. As an alternative, after the image data Ro, Go, Bo, or Rp, Gp, Bp are obtained, they may then be converted into complementary color data representing cyan, magenta and yellow, by determining 1's complement. In this case, the same effects will be realized.

Furthermore, in Embodiment 1 described above, the processing was performed by the hardware configuration of FIG. **1**. Needless to say, the same processing can be performed by software in the color conversion device, and in this case, the same effects as those of Embodiment 1 will be provided.

Moreover, the conversion characteristics of the gray scale converters **15***a*, **15***b* and **15***c* can be determined taking into consideration the characteristics of the output device connected to receive the output of the color conversion device, and are not restricted to gamma correction characteristics, and may be a linear characteristics in an extreme case. However, even in the case of a linear characteristics, by varying the inclination, the level balance of the output signals can be adjusted.

Embodiment 2

In Embodiment 1, the hue data r, g, b, y, m and c, and the maximum and minimum values β and α were calculated based on the inputted image data of red, green and blue so as to obtain the calculation terms for the respective hues, and after the matrix calculation, the image data red, green and blue were obtained. But the image data of red, green and blue may first be converted into complementary color data of cyan, magenta and yellow, by determining 1's complement of the input image data, and then color conversion may be executed by inputting the complementary color data of cyan, magenta and yellow.

FIG. **15** is a block diagram showing an example of configuration of a color conversion device of Embodiment 2 of the present invention. In describing Embodiment 2, the inputted image data of red, green and blue are denoted by Rj, Gj and Bj. Reference numerals **3**, **4**, **5**, **6**, **15***a*, **15***b* and **15***c* denote the same members as those described with reference to FIG. **1** in connection with Embodiment 1. Reference numeral **14** denotes a complement calculator; **1***b*, a minimum and maximum calculator for generating maximum and minimum values β and α of complementary color data and an identification code for indicating, among the six hue data, data which are zero; and **2***b*, a hue data calculator for calculating hue data r, g, b, y, m and c based on complementary color data Ci, Mi and Yi from the complement calculator **14** and outputs from the minimum and maximum calculator **1***b*.

Next, the operation will be described. The complement calculator **14** receives the image data Rj, Gj and Bj, and outputs complementary color data Ci, Mi and Yi obtained by determining 1's complements. The minimum and maximum calculator **1***b* outputs the maximum and minimum values β and α of each of these complementary color data and the identification code S**1**.

Then, the hue data calculator **2***b* receives the complementary color data Ci, Mi and Yi and the maximum and minimum values β and α from the minimum and maximum calculator **1***b*, performs subtraction of

r=β−Ci,
g=β−Mi,
b=β−Yi,
y=Yi−α,
m=Mi−α, and
c=Ci−α

and outputs six hue data r, g, b, y, m and c. Here, at least two among these six hue data are zero. The identification code S**1** outputted from the minimum and maximum calculator **1***b* is used for specifying, among the six hue data, data which is zero. The value of the identification code S**1** depends on which of Ci, Mi and Yi the maximum and minimum values β and α are. Relations between the data among the six hue data which are zero, and the values of the identification code S**1** are the same as those in Embodiment 1, and thus further explanation will be omitted.

Then, the six hue data r, g, b, y, m and c outputted from the hue data calculator **2***b* are sent to the polynomial calculator **3**, and the hue data c, m and y are also sent to the matrix calculator **4**. The polynomial calculator **3** also receives the identification code S**1** outputted from the minimum and maximum calculator **1***b*, and performs calculation by selecting, from the hue data, two data Q**1** and Q**2** which are not zero, and from the hue data y, m and c, two data P**1** and P**2** which are not of a value zero. This operation is identical to that described with reference to FIG. **2** in connection with Embodiment 1, so that detailed description thereof is omitted.

The output of the polynomial calculator **3** is supplied to the matrix calculator **4**, and the coefficient generator **5** generates the calculation coefficients U (Fij) and fixed coefficients U (Eij) for the polynomial data based on the identification code S**1**, and sends the same to the matrix calculator **4**. The matrix calculator **4** receives the hue data c, m and y from the hue data calculator **2***b*, the polynomial data T**1** to T**5** from the polynomial calculator **3** and the coefficients U from the coefficient generator **5**, and outputs the results of calculation according to the following formula (8) as image data C**1**, M**1** and Y**1**.

$$\begin{bmatrix} C1 \\ M1 \\ Y1 \end{bmatrix} = (Eij)\begin{bmatrix} c \\ m \\ y \end{bmatrix} + (Fij)\begin{bmatrix} T1 \\ T2 \\ T3 \\ T4 \\ T5 \end{bmatrix} \tag{8}$$

In the formula (8), for (Eij), i=1 to 3 and j=1 to 3, and for (Fij), i=1 to 3 and j=1 to 5.

The operation at the matrix calculator **4** is similar to that described with reference to FIG. **5** in connection with Embodiment 1, but the inputted hue data is c (or m, y), and C**1** (or M**1**, Y**1**) is calculated and outputted. The detailed description thereof is therefore omitted.

The synthesizer **6** receives the image data C**1**, M**1** and Y**1** from the matrix calculator **4** and the minimum value α outputted from the minimum and maximum calculator **1***b* representing the achromatic data, performs addition, and outputs image data Co, Mo and Yo. The equation used for obtaining the image data color-converted by the color-conversion method of FIG. **15** is therefore given by the following formula (2).

$$\begin{bmatrix} Co \\ Mo \\ Yo \end{bmatrix} = (Eij)\begin{bmatrix} c \\ m \\ y \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \end{bmatrix} + \begin{bmatrix} \alpha \\ \alpha \\ \alpha \end{bmatrix} \tag{2}$$

In the formula (2), for (Eij), i=1 to 3 and j=1 to 3, and for (Fij), i=1 to 3 and j=1 to 18, and

h**1**r=min (m, y),
h**1**g=min (y, c),
h**1**b=min (c, m),
h**1**c=min (g, b),
h**1**m=min (b, r),
h**1**y=min (r, g),
h**2**ry=min (aq**1***h**1**y, ap**1***h**1**r),
h**2**rm=min (aq**2***h**1**m, ap**2***h**1**r),
h**2**gy=min (aq**3***h**1**y, ap**3***h**1**g),
h**2**gc=min (aq**4***h**1**c, ap**4***h**1**g),
h**2**bm=min (aq**5***h**1**m, ap**5***h**1**b), and
h**2**bc=min (aq**6***h**1**c, ap**6***h**1**b), and

aq**1** to aq**6** and ap**1** to ap**6** indicate calculation coefficients generated by the calculation coefficient generator **11** of FIG. **2**.

The difference between the number of calculation terms in the formula (2) and the number of calculation terms in FIG. **15** is that FIG. **15** shows a method of calculation for each pixel excluding the calculation terms which are of a value zero, while the formula (2) represents a general formula for a set of pixels. In other words, eighteen polynomial data for one pixel of the formula (2) can be reduced to five effective data, and this reduction is achieved by exploiting a characteristic of the hue data.

The combination of effective data is changed according to image data of the target-pixel. For all image data, all the polynomial data can be effective.

The calculation terms output from the polynomial calculator based on the formula (2) are identical to those of the formula (1) in Embodiment 1. Thus, relations between the six hues and inter-hue areas and effective calculation terms are the same as those shown in FIG. **11**A and FIG. **11**B. Therefore, as in Embodiment 1, in the coefficient generator **5**, by changing the coefficients for an effective calculation term for a hue or for an inter-hue area to be adjusted, only the target hue or inter-hue area can be adjusted. In addition, by changing the coefficients in the calculation coefficient generator **11** in the polynomial calculator **3**, part of the inter-hue area where the calculation term in the inter-hue area is effective can be changed without giving any influence to the other hues.

Here, an example of coefficients generated by the coefficient generator **5** of Embodiment 2 are the coefficients U (Eij) of the formula (5), as in Embodiment 1. If the coefficients U (Fij) are all zero, color conversion is not executed. Also, if those of the coefficients U (Fij) of the formula (7) which relate to the second-order calculation terms which are product terms are all zero, adjustment is performed based on the coefficients for the first and second comparison-result data, which are first-order calculation terms, and linear adjustment on only a hue or an inter-hue area can be achieved. By setting coefficients relating to a first-order calculation term for a hue or an inter-hue area to be changed and setting other coefficients to zero, only the target hue or inter-hue area can be adjusted.

As apparent from the foregoing, by changing the coefficients for the product terms and first comparison-result data relating to specific hues, it is possible to adjust only the target hue among the six hues of red, blue, green, yellow, cyan and magenta, and by changing the coefficients for the second comparison-result data, it is possible to vary the colors in the six inter-hue areas of red-yellow, yellow-green, green-cyan, cyan-blue, blue-magenta, and magenta-red. The adjustment of each hue or inter-hue area can be achieved independently, i.e., without influencing other hues or other inter-hue areas.

Each of the foregoing product terms is a second-order calculation for chroma, and each of the first and second comparison-result data is a first-order calculation for chroma. Accordingly, by using the product term and the first and second comparison-result data, the non-linearity of an image-printing or the like can be varied for chroma.

Moreover, by performing the gray scale conversion at the gray scale converters **15***a*, **15***b* and **15***c*, it is possible to compensate for third-order or higher-order non-linearities, or complicated, non-linear characteristics (e.g., S-shaped characteristics) such as the one which liquid-crystal displays exhibit, and which can be obtained just by combining the first-order and second-order calculations.

Accordingly, it is possible to obtain color conversion methods or color conversion devices which can change the conversion characteristics flexibly, without requiring a large-capacity memory. It is noted that the gray scale converters can be realized by a one-dimensional look-up table, and its size is much smaller than the three-dimensional look-up table.

Furthermore, in Embodiment 2 described above, the processing was performed by the hardware configuration of FIG. **15**. Needless to say, the same processing can be performed by software in the color conversion device, and in this case, the same effects as those of Embodiment 2 will be provided.

Moreover, the conversion characteristics of the gray scale converters **15***a*, **15***b* and **15***c* can be determined taking into consideration the characteristics of the output device connected to receive the output of the color conversion device, and are not restricted to gamma correction characteristics, and may be a linear characteristics in an extreme case. However, even in the case of a linear characteristics, by varying the inclination, the level balance of the output signals can be adjusted.

Embodiment 3

In Embodiment 1, part of an example of configuration of the matrix calculator **4** is as shown in the block diagram of FIG. **5**, and the hue data and the respective calculation terms and the minimum value α among the image data Ri, Gi and Bi which is achromatic data are added together to produce the image data Ro, Go, Bo, as shown in the formula (1). It is possible to adopt a configuration shown in FIG. **16** in which coefficients for the minimum value α which is achromatic data are generated in the coefficient generator and the matrix calculation is performed on the minimum value α as well, to adjust the achromatic component.

FIG. **16** is a block diagram showing an example of configuration of a color conversion device of Embodiment 3 of the present invention. In the figure, reference numerals **1**, **2**, **3**, **15***a*, **15***b* and **15***c* denote members identical to those described with reference to FIG. **1** in connection with Embodiment 1. Reference numeral **4***b* denotes a matrix calculator, and **5***b* denotes a coefficient generator.

The operation will next be described. The determination of the maximum value β, the minimum value α, and the identification code S**1** from the inputted data at the minimum and maximum calculator **1**, the calculation of the six hue data at the hue data calculator **2**, and the determination of the calculation terms at the polynomial calculator **3** are identical to those of Embodiment 1, and detailed description thereof is therefore omitted.

The coefficient generator **5***b* in FIG. **16** generates the calculation coefficients U (Fij) and the fixed coefficients U (Eij) of the polynomial data based on the identification code S**1** and sends them to the matrix calculator **4***b*. The matrix calculator **4***b* receives the hue data r, g, and b from the hue data calculator **2**, the polynomial data T**1** to T**5** from the polynomial calculator **3**, the minimum value α from the minimum and maximum calculator **1**, and the coefficients U from the coefficient generator **5***b*, and performs calculation thereon. The equation used for the calculation for adjusting the achromatic component as well is represented by the following formula (9).

$$\begin{bmatrix} Ro \\ Go \\ Bo \end{bmatrix} = (Eij)\begin{bmatrix} r \\ g \\ b \end{bmatrix} + (Fij)\begin{bmatrix} T1 \\ T2 \\ T3 \\ T4 \\ T5 \\ \alpha \end{bmatrix} \tag{9}$$

In the formula (9), for (Eij), i=1 to 3 and j=1 to 3, and for (Fij), i=1 to 3 and j=1 to 6.

FIG. **17** is a block diagram showing an example of configuration of the matrix calculator **4***b*. In FIG. **17**, reference numerals **12***a* to **12***f* and **13***a* to **13***f* denote members identical to those in the matrix calculator **4** of Embodiment 1. Reference numeral **12***g* denotes a multiplier receiving the minimum value α from the minimum and maximum calculator **1** indicating the achromatic component, and the coefficients U from the coefficient generator **5***b*, and performs multiplication thereon. Reference numeral **13***f* denotes an adder.

Next, the operation will be described. The multipliers **12***a* to **12***f* receive the hue data r, the polynomial data T**1** to T**5** from the polynomial calculator **3** and the coefficients U (Eij) and U (Fij) from the coefficient generator **5**, and then output the products thereof. The adders **13***a* to **13***e* add the products and sums. These operations are identical to those of the matrix calculator **4** in Embodiment 1. The multiplier **12***g* receives the minimum value α among the image data Ri, Gi and Bi, from the minimum and maximum calculator **1** which corresponds to the achromatic component, and the coefficients U (Fij) from the coefficient generator **5***b*, and performs multiplication, and outputs the product to the adder **13***f*, where the product is added to the output of the adder **13***e*, and the sum total is output as the image data Ro. In the example of FIG. **17**, if the hue data r is replaced by g or b, the image data Go or Bo is calculated.

The part of the coefficients (Eij) and (Fij) corresponding to the hue data r, g and b are used. In other words, if three configurations, each similar to that of FIG. **17**, are used in parallel for the hue data r, g and b, matrix calculation can be performed at a higher speed.

The equation for determining the image data is represented by the following formula (3).

$$\begin{bmatrix} Ro \\ Go \\ Bo \end{bmatrix} = (Eij)\begin{bmatrix} r \\ g \\ b \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \\ \alpha \end{bmatrix} \tag{3}$$

In the formula (3), for (Eij), i=1 to 3 and j=1 to 3, and for (Fij), i=1 to 3 and j=1 to 19.

The difference between the number of calculation terms in the formula (3) and the number of calculation terms in FIG. **16** is that, as in Embodiment 1, FIG. **16** shows a method of calculation for each pixel excluding the calculation terms which are of a value zero, while the formula (3) represents a general formula for a set of pixels. In other words, nineteen polynomial data for one pixel of the formula (3) can be reduced to six effective data, and this reduction is achieved by exploiting a characteristic of the hue data.

The combination of effective data is changed according to image data of the target pixel. For all image data, all the polynomial data can be effective.

If all the coefficients relating to the minimum value α are "1", the achromatic data is not converted, and will be of the same value as the achromatic data in the inputted data. If the coefficients used in the matrix calculation are changed, it is possible to choose between reddish black, bluish black, and the like, and the achromatic component can be adjusted.

As apparent from the foregoing, by changing the coefficients for the product term and first comparison-result data relating to specific hues, and the second comparison-result data relating to the inter-hue areas, it is possible to adjust only the target hue or inter-hue area among the six hues of red, blue, green, yellow, cyan and magenta, and the six inter-hue areas, without influencing other hues and inter-hue areas. By changing the coefficients relating to the minimum value α which is the achromatic data, it is possible to adjust only the achromatic component without influencing the hue components, and choose between a standard black, reddish black, bluish black and the like.

In Embodiment 3 described above, the image data Ro, Go and Bo are obtained after the calculation according to the formula (3), and image data Rp, Gp, Bp are obtained after the gray scale conversion. As an alternative, after the output image data Ro, Go, Bo or Rp, Gp, Bp are obtained, they may be converted to data representing cyan, magenta and yellow, by determining 1's complement. If the coefficients used in the matrix calculation can be changed for the respective hues, the inter-hue areas, and the minimum value α which is achromatic data, effects similar to those discussed above can be obtained.

As in Embodiment 1 described above, in Embodiment 3, as well, the same processing can be performed by software in the color conversion device, and in this case, the same effects as those of Embodiment 3 will be provided.

Moreover, the conversion characteristics of the gray scale converters **15***a*, **15***b* and **15***c* can be determined taking into consideration the characteristics of the output device connected to receive the output of the color conversion device, and are not restricted to gamma correction characteristics, and may be a linear characteristics in an extreme case. However, even in the case of a linear characteristics, by varying the inclination, the level balance of the output signals can be adjusted.

Embodiment 4

Embodiment 2 was configured to add the hue data, the calculation terms, and the minimum value α which is achromatic data, as shown in the formula (2). As an alternative, the configuration may be such that coefficients for the minimum value α which is achromatic data is generated at the coefficient generator and the matrix calculation is performed on the minimum value α as well, as shown in FIG. **18**, so that the achromatic component is thereby adjusted.

FIG. **18** is a block diagram showing an example of configuration of color conversion device according to Embodiment **4** of the invention. In the figure, reference numerals **14**, **1***b*, **2***b*, **3**, **15***a*, **15***b* and **15***c* denote members identical to those described with reference to FIG. **15** in connection with Embodiment 2, and reference numerals **4***b* and **5***b* denote members identical to those described with reference to FIG. **16** in connection with Embodiment 3.

The operation will next be described. The image data Rj, Gj, Bj are input to the complement calculator **14** to obtain the complementary data Ci, Mi, Yi by the process of determining 1's complement. The determination of the maximum value β, the minimum value α and the identification code S1 at the minimum and maximum calculator **1***b*, the calculation of the six hue data at the hue data calculator **2***b*, and the determination of the calculation terms at the polynomial calculator **3** are identical to those in the case of the complementary data Ci, Mi, Yi in Embodiment 2. The detailed description thereof are therefore omitted.

The coefficient generator **5***b* in FIG. **18** generates the calculation coefficients U (Fij) and the fixed coefficients U (Eij) of the polynomial data based on the identification code S**1** and sends them to the matrix calculator **4***b*. The matrix calculator **4***b* receives the hue data c, m, and y from the hue data calculator **2***b*, the polynomial data T**1** to T**5** from the polynomial calculator **3**, the minimum value α from the minimum and maximum calculator **1**, and the coefficients U from the coefficient generator **5***b*, and performs calculation thereon. The equation used for the calculation is represented by the following formula (10), and the achromatic component is adjusted.

$$\begin{bmatrix} Co \\ Mo \\ Yo \end{bmatrix} = (Eij)\begin{bmatrix} c \\ m \\ y \end{bmatrix} + (Fij)\begin{bmatrix} T1 \\ T2 \\ T3 \\ T4 \\ T5 \\ \alpha \end{bmatrix} \quad (10)$$

In the formula (10), for (Eij), i=1 to 3 and j=1 to 3, and for (Fij), i=1 to 3 and j=1 to 6.

The operation at the matrix calculator **4**b is similar to that described with reference to FIG. **17** in connection with Embodiment 3, but the inputted hue data is c (or m, y), and Co (or Mo, Yo) is calculated and outputted. The detailed description thereof is therefore omitted.

The equation for determining the image data is represented by the following formula (4).

$$\begin{bmatrix} Co \\ Mo \\ Yo \end{bmatrix} = (Eij)\begin{bmatrix} c \\ m \\ y \end{bmatrix} + (Fij)\begin{bmatrix} c*m \\ m*y \\ y*c \\ r*g \\ g*b \\ b*r \\ h1r \\ h1g \\ h1b \\ h1c \\ h1m \\ h1y \\ h2ry \\ h2rm \\ h2gy \\ h2gc \\ h2bm \\ h2bc \\ \alpha \end{bmatrix} \quad (4)$$

In the formula (4), for (Eij), i=1 to 3 and j=1 to 3, and for (Fij), i=1 to 3 and j=1 to 19.

The difference between the number of calculation terms in the formula (4) and the number of calculation terms in FIG. **18** is that, as in Embodiment 2, FIG. **18** shows a method of calculation for each pixel excluding the calculation terms which are of a value zero, while the formula (4) represents a general formula for a set of pixels. In other words, nineteen polynomial data for one pixel of the formula (4) can be reduced to six effective data, and this reduction is achieved by exploiting a characteristic of the hue data.

The combination of effective data is changed according to image data of the target pixel. For all image data, all the polynomial data can be effective.

If all the coefficients relating to the minimum value α are "1", the achromatic data is not converted, and will be of the same value as the achromatic data in the inputted data. If the coefficients used in the matrix calculation are changed, it is possible to choose between reddish black, bluish black, and the like, and the achromatic component can be adjusted.

As apparent from the foregoing, by changing the coefficients for the product term and first comparison-result data relating to specific hues, and the second comparison-result data relating to the inter-hue areas, it is possible to adjust only the target hue or inter-hue area among the six hues of red, blue, green, yellow, cyan and magenta, and the six inter-hue areas, without influencing other hues and inter-hue areas. By changing the coefficients relating to the minimum value α which is the achromatic data, it is possible to adjust only the achromatic component without influencing the hue components, and choose between a standard black, reddish black, bluish black and the like.

As in Embodiment 1 described above, in Embodiment 4, as well, the same processing can be performed by software in the color conversion device, and in this case, the same effects as those of Embodiment 4 will be provided.

Moreover, the conversion characteristics of the gray scale converters **15**a, **15**b and **15**c can be determined taking into consideration the characteristics of the output device connected to receive the output of the color conversion device, and are not restricted to gamma correction characteristics, and may be a linear characteristics in an extreme case. However, even in the case of a linear characteristics, by varying the inclination, the level balance of the output signals can be adjusted.

Embodiment 5

In Embodiment 2 and Embodiment 4, the image data Ci, Mi, Yi are obtained by determining 1's complement of input image data Rj, Gj and Bj. Similarly, the image data Ri, Gi, Bi used in Embodiment 1 may be those obtained by 1's complement of input image data representing cyan, magenta and yellow, Cj, Mj and Yj. For the determination of the 1's complement of the input image data Cj, Mj, Yj, a complement calculator which is similar to the complement calculator **14** in FIG. **15** or FIG. **18** but which receives the image data Cj, Mj, Yj may be used. FIG. **19** shows an example of color conversion device having such a complement calculator denoted **14**b. Apart from the addition of the complement calculator **14**b, the configuration of the color conversion device of FIG. **19** is similar to the color conversion device of FIG. **1**. Similar modification may be made to the color conversion device of Embodiment 3 shown in FIG. **16**.

Modifications described in connection with Embodiment 1 to Embodiment 4 can also be applied to Embodiment 5.

What is claimed is:

1. A color conversion device for converting first color data into second color data by performing pixel-by-pixel color conversion, the color conversion device comprising:

a coefficient generator for generating matrix coefficients;

a first calculator for generating a first calculation term which is substantially effective for one of hues of red, green, and blue, and a second calculation term which is substantially effective for one of hues of cyan, magenta, and yellow, based on the first color data;

a second calculator for generating a third calculation term which is substantially effective for only one inter hue region between adjacent hues of red, green, blue, cyan, magenta, and yellow using the first calculation term and the second calculation term;

a matrix calculator for performing a matrix calculation using the matrix coefficients, the first calculation term, the second calculation term, and the third calculation term; and

a tone converter for converting tone characteristics of the color data obtained by the matrix calculation to generate the second color data, wherein each of the first calculation term and the second calculation term includes a second order term.

2. A method for converting first color data into second color data by performing pixel by pixel color conversion, the method comprising:

generating matrix coefficients;

generating a first calculation term which is substantially effective for one of hues of red, green, and blue, and a second calculation term which is substantially effective for one of hues of cyan, magenta, and yellow, based on the first color data;

generating a third calculation term which is substantially effective for only one inter hue region between adjacent hues of red, green, blue, cyan, magenta, and yellow using the first calculation term and the second calculation term;

performing a matrix calculation using the matrix coefficients, the first calculation term, the second calculation term, and the third calculation term; and

converting tone characteristics of the color data obtained by the matrix calculation to generate the second color data,

wherein each of the first calculation term and the second calculation term includes a second order term.

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